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Simulation of the Hydrologic-Economic Flow System in an Agricultural Area

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CHAPTER I

INTRODUCTION

General

Future planning and management of natural resources must be based upon optimum use considerations which are highly dependent upon the concept of economic efficiency. Economic efficiency may be defined as the relationship between the cost of particular inputs and the return of the resulting outputs. Therefore, economic efficiency in the management of a resource system is concerned with maximizing net benefits.

Optimizing the beneficial use of an existing water resource system depends upon an accurate quantitative assessment of the net benefits of various management alternatives. Planning for water resource use is a complex operation requiring careful consideration of the entire system, which is a function of the associated hydrologic flow system and the related economic production functions. An appropriate description of a water resource system, therefore, includes the hydrologic system, the economic system, and the functions which relate the hydrologic and economic systems.

Simulation is a useful technique in water resources planning and management. Application of this technique involves synthesis of fundamental mathematical relationships for hydrologic and economic processes into a working model of the system. Comprehensive modeling of the hydrology of a river basin began in 1956 with the Harvard Water Resources Program (Hufschmidt and Fiering, 1966). The purpose of that program was to improve the methodology for managing water resource systems.

Simulation of economic systems has been attempted in the form of business cycle economics modeled from historical records. Holland and Gillespie (1963) simulated the recent history of the economy of India and used their model to test various alternative development programs. Manetsch (1965) applied the simulation technique to an analysis of the economic system within the softwood-plywood industry of the United States.

In the study presented herein, a procedure for simultaneous modeling of the hydrologic and agricultural economic systems within a study area is developed. The objectives of this study are to:

1. Develop, improve, and evaluate basic relationships which link the hydrologic and economic flow systems.
2. Develop a comprehensive model consisting of the linked hydrologic and economic flow systems and to synthesize this model on an electronic computer.
3. Apply the computer model to a study of water values within a particular drainage basin.
4. Demonstrate through a sensitivity analysis the ability of the model to indicate the relative importance of various parameters and processes within the system.
5. Demonstrate the usefulness of the model in determining the effects of various management practices on system parameters and output functions.

The general hydrologic model with some modifications developed by Riley et al. (1966) for Circle Valley, Utah, was adopted. The hydrologic model was programmed and verified on an analog computer. The verified computer program was then written in Fortran IV Language for operation on a digital computer. An economic model pertaining to agricultural production within the area was formulated and programmed on the digital computer. The two models were linked by production functions associated with each agricultural crop.

Through the comprehensive hydro-economic model, the consequences of various management alternatives under a variety of constraining assumptions were traced through time. For example, water values were investigated by diverting water to alternate uses from particular phases of agriculture and determining change in net income.

The technique developed under this study represents a valuable asset to those faced with decisions regarding the utilization of existing water resources. Specifically, some of the benefits to be realized are:

1. The model substantially aids in evaluating and understanding the basic processes which link the hydrologic and economic flow systems.
2. Because it is based on fundamental relationships, the model has wide application to the problems of water resources planning and management.
3. The model provides insight into the relative importance of the various processes within the hydrologic-economic flow system. In addition, interactions between the different processes in the systems are examined.
4. The relative importance of data and other available knowledge with respect to the various parts of the entire system can be objectively assessed. For example, the study indicated that additional research is needed to completely define agricultural production functions under various conditions of soil, water, and management.
5. The marginal value of water for agriculture under various conditions and constraints is readily estimated.
6. A means is provided for predicting the economic impact on the farm unit due to changes in the water supply. This analysis can be applied for both short and long run economic considerations.

The Experimental Area

The mathematical model of the hydrologic-economic system was tested and verified with data from Cache Valley, located in Cache County, Utah, and Franklin County, Idaho. Cache Valley was selected as the study area for the following reasons.

1. Cache Valley has three important facilities required for a study of this nature: (a) convenience of easy and frequent inspection; (b) availability of data; and (c) the results of any study conducted in the area are readily applicable over a wide surrounding region and to areas with similar features.
2. The study area is well defined from physical and economic standpoints.
3. Basic hydrologic and economic data are available from records such as the U. S. Bureau of Reclamation (1962a and 1962b), and studies by Hiskey (1968).
4. The Utah Water Research Laboratory and Utah State University lie within the study area. This facilitated ready and frequent consultations with those who earlier conducted relevent investigations in the study area and with the experts in the field.
5. A variety of agricultural crops are grown in the area. Such variety allowed the model to be tested and the results evaluated under more general conditions.
6. The Cache Valley study of DeTray (1967) has given a good initial grounding for this study. This present study was actually planned as a follow-up investigation of the study by DeTray.

DeTray made a methodological study of the simulation techniques of analysis with special reference to developing economic-hydrologic models of real but complex water resource systems. He studied the utility of various techniques of simulation in predicting the economic impact of changes in water supply and of developing aggregate social values for water. DeTray concluded from his study that the simulation approach is well suited for analyzing and studying large complex water resource systems, including Cache Valley. Actual simulation of Cache Valley is, therefore, attempted in this study.

Location

Cache Valley is a small contiguous unit located in northern Utah and neighboring southeastern Idaho (Figure 1.1). The study area is situated roughly between $41^{\circ}30'$ and $42^{\circ}15'$ north latitudes and between $111^{\circ}50'$ and $112^{\circ}05'$ west longitudes and forms a part of the Bear River drainage (Figure 1.2). Cache Valley is oriented in a general north-south direction and is approximately 60 miles long and 15 miles wide. The actual modeled area of Cache Valley is 333 square miles.

Boundary

The hydrologic-economic investigation was primarily concerned with agriculturally related economics which are affected by natural and artificially imposed hydrologic conditions. The modeled area (Figure 1.3) included the irrigated cropland and lower lands dominated by phreatophytes. The entire valley floor was considered as a single space unit in the model. A small portion of the uncultivated area is included in Logan City and other urban areas. The urban areas are assumed to consume about half the water used by the same area of pasture land (Narayana et al., 1968). The pervious portion of the city area is usually in the form of irrigated lawns.

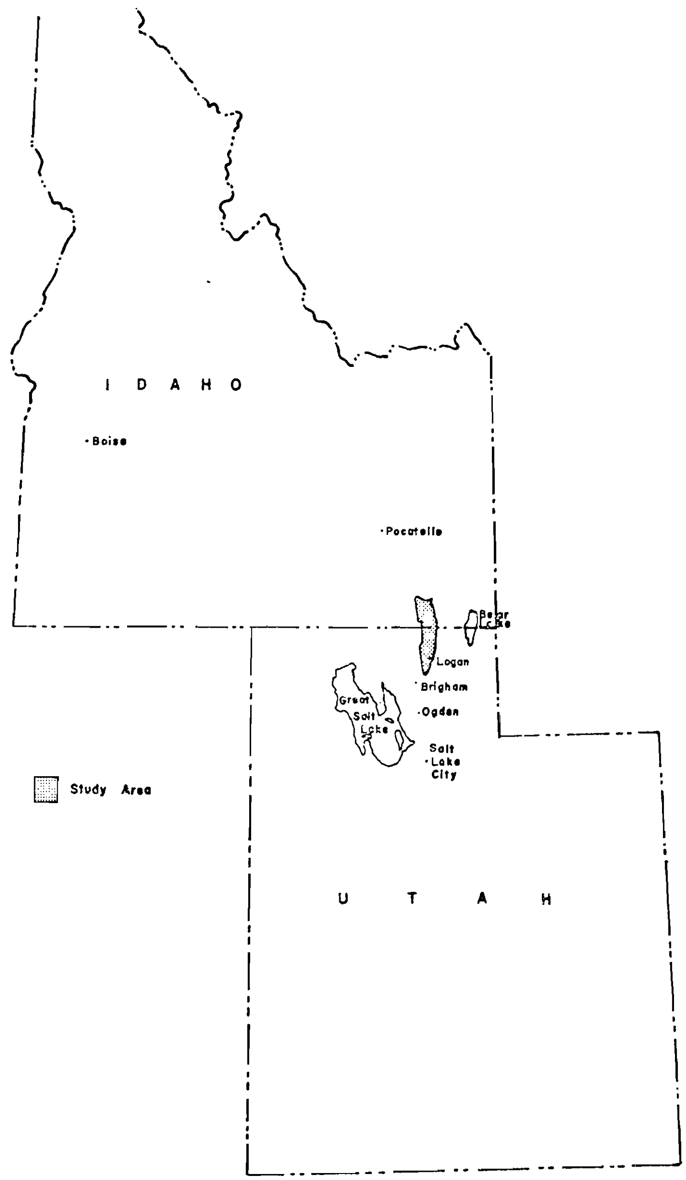

Figure 1.1. General location of the Cache Valley subbasin.

Topography

Cache Valley is generally flat with an average elevation of about 4,500 feet and is surrounded by mountains which exceed 9,000 feet and comprise a large portion of the total watershed. Runoff from the Cache Valley is discharged into Cutler Reservoir by the major drainages which include the Bear,

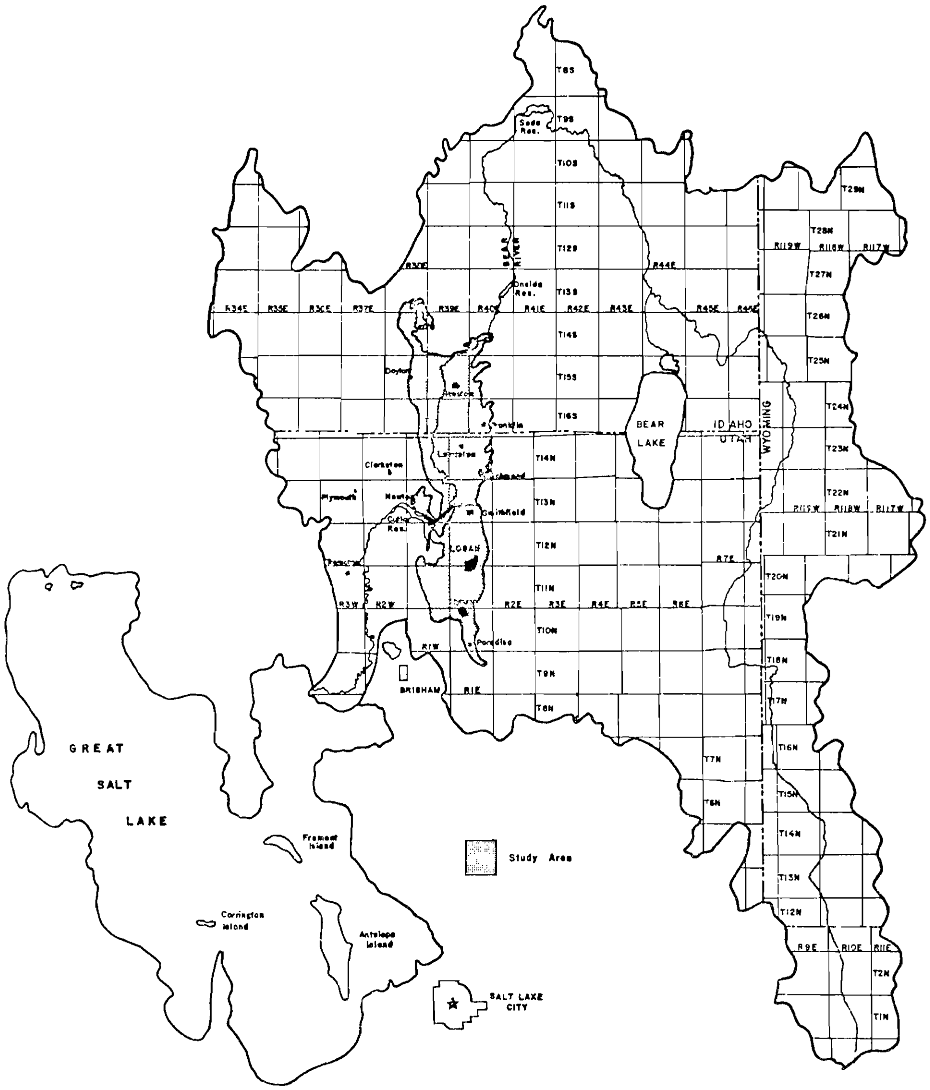

Figure 1.2. Location of Cache Valley within the Bear River drainage.

Logan, Cub, and Little Bear Rivers. Bear River is the largest stream in the watershed and flows southward from Idaho.

Vegetative cover

The cropping pattern used for model verification is taken from land use inventory maps prepared by Haws (1969a). Cache Valley was mapped during the summer of 1966; the maps were completed in 1967. The summary of values used is shown in Table 8.1. For this study, the areas listed as small truck crops such as tomatoes, beans, and peas, are included with sugar beets because they require a similar amount of labor and provide the same range of net returns to farm management.

The phreatophytes are divided into two groups: (a) those growing on land (ditch banks, etc.) and (b) those growing in water (low marsh lands). Land phreatophytes comprise about 75 percent of the total phreatophyte area.

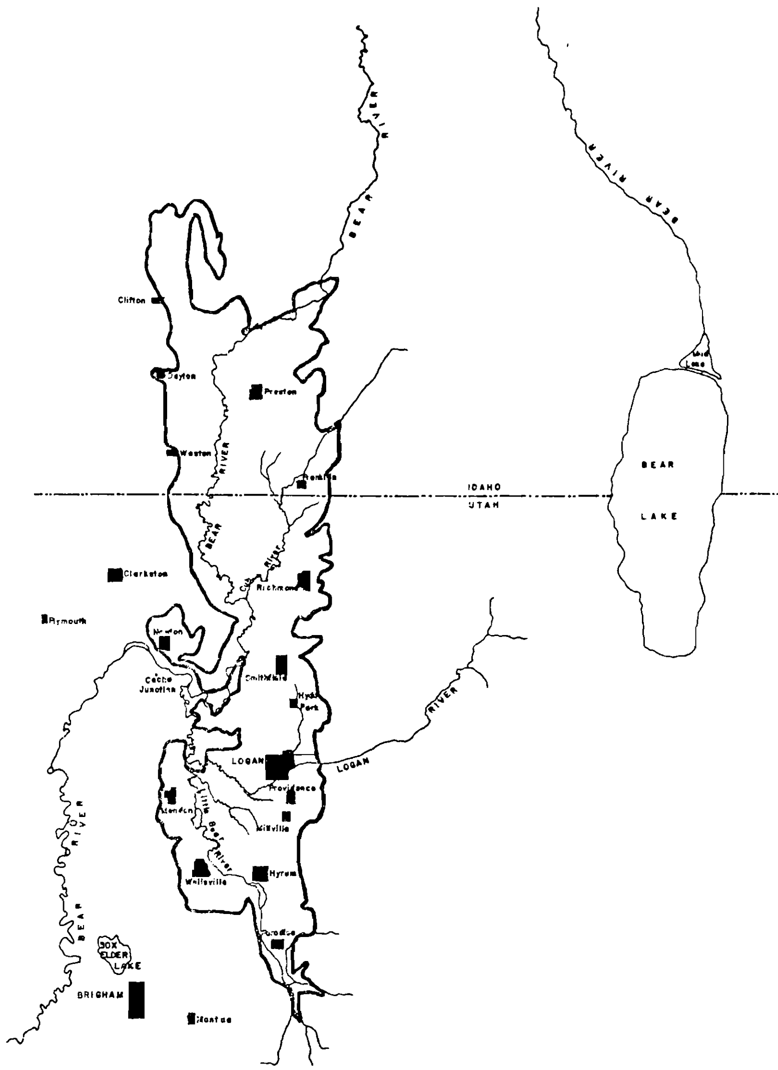

Figure 1.3. Study area boundary of Cache Valley.

The land-based phreatophytes are treated as a crop which consumes 2 percent of the diverted water. Evapotranspiration from land phreatophytes is, however, limited by a soil moisture deficiency late in the summer.

Water-based phreatophytes are not treated as a crop but are assumed to abstract water from the surface supply of marshy areas at the same rate as the potential evapotranspiration.

Climate

Cache Valley has a temperate and semiarid climate with light rainfall and low humidity. The average annual precipitation is 14.80 inches. Average monthly precipitation values for Cache Valley are shown by Figure 1.4.

The mean annual temperature for the study area is 45.4°F, with a maximum of 105°F, a minimum temperature of -32°F. Average monthly temperatures for Cache Valley are shown in Figure 1.5.

The frost free period (consecutive days when the temperature is 32°F or above) in the valley is on the average 123 days (U. S. Bureau of Reclamation, 1962c). The climate permits a wide range of temperate climate field crops such as wheat, barley alfalfa, pasture, field corn, sugar beets, peas, green beans, canning corn, and truck crops.

Geology

In a broad sense, the geology of any area determines the capacity of surface storage as well as groundwater storage and percolation rates (Morris and Johnson, 1967). The direction and the rate of groundwater movement also depends upon the geology of the area. The geology of Cache Valley is particularly important because of the comparatively large subsurface inflow from the surrounding mountains. Geological studies related to this area have been done by Gilbert (1890), Williams (1958, 1962), and Beer (1967).

Bedrock of the Cache Valley watershed is described by Beer (1967) as consisting of Precambrian, Paleozoic, and Tertiary rocks of limestone and dolomite, shale, sandstone, and conglomerate, quartzite and phyllite, and volcanic tuff. The valley fill contains unconsolidated quaternary sediments of gravel, sand, silt, and clay of lacustrine and fluvial origin.

Groundwater

The Cache Valley groundwater basin varies in aquifer productivity, water temperature, and water quality. The unusual geology of the area has been responsible for the existence of groundwater occurring under both water table and artesian conditions.

Aquifers in the Logan area are highly productive and are composed of well sorted gravels and sandy gravels. Wells in this area produce up to 4,500 gallons per minute and obtain water from aquifers with transmissibilities up to one million/gpd/ft and specific capacities ranging from 100 to 350 gpm/ft (Beer, 1967). Aquifers away from the Logan area are less productive.

Water-table conditions in the Logan area change to artesian conditions towards the west. About 2,000 wells, most of which are of the flow-type, are operated in these aquifers (Bjorklund, 1968).

Soils

The soils of Cache Valley originated from a wide variety of rocks and minerals which were transported into the valley by the Bear River and by tributary streams (U. S. Bureau of Reclamation, 1962c). Much of the soil material was deposited in ancient Lake Bonneville. The sand and gravel materials were deposited at the periphery of the valley as fans and lake terraces. Finer textured lacustrine clay sediments settled in the deeper and more quiet waters of the lake. They are widely distributed on the interior of the valley. Alluvial sediments were deposited along the meandering courses of rivers and streams which traversed the valley floor. Most of the land has good water transmission properties and adequate available moisture capacity. Natural precipitation and irrigation have generally leached most of the toxic chemical constituents from higher lands and transported them to the lower areas on the valley floor. The soils are mostly silt loams with infiltration rates normally ranging between 0.6 and 1.3 inches per hour.

Many of the low valley lands produce only poor quality pasture grasses because of waterlogging, salinity, and alkali. Other lands now produce only light crops of wild hay and some are almost completely non-productive because of the concentration of harmful salts. Gardner and Israelsen (1954) estimate that over 20,000 acres of Cache Valley bottom land can be made productive through adequate drainage.

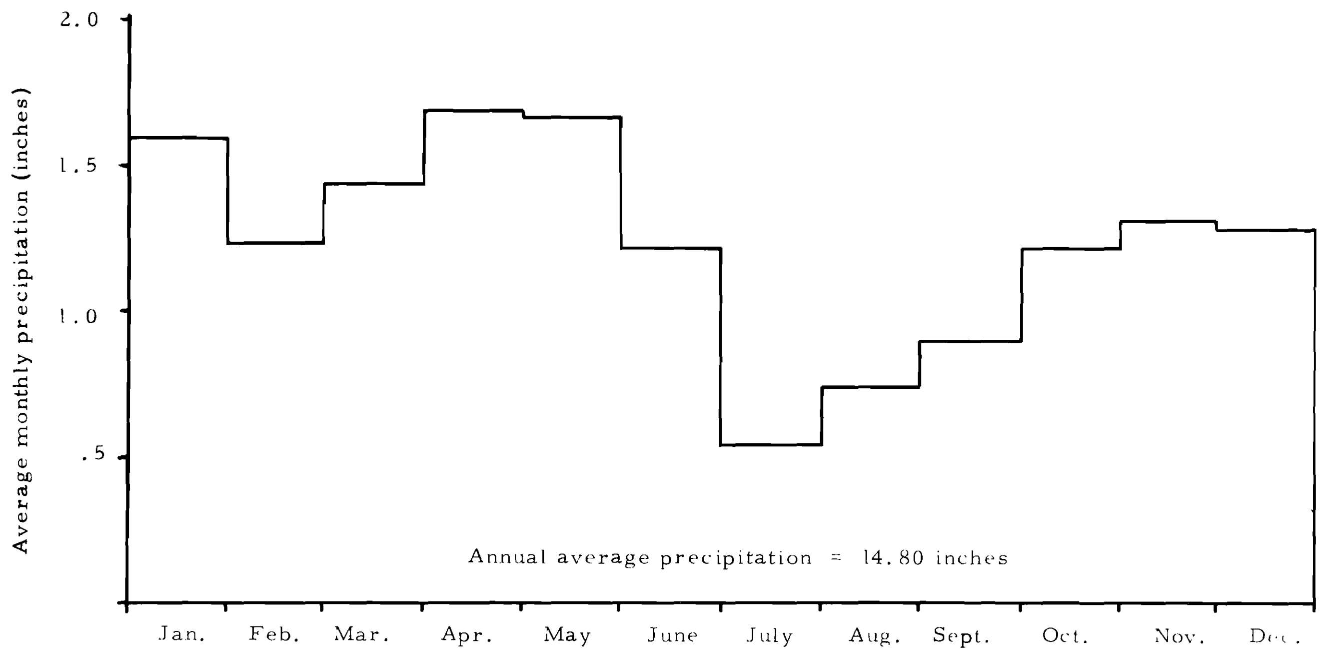

Figure 1.4. Average monthly precipitation for the irrigated crop land of Cache Valley (1931-1965).

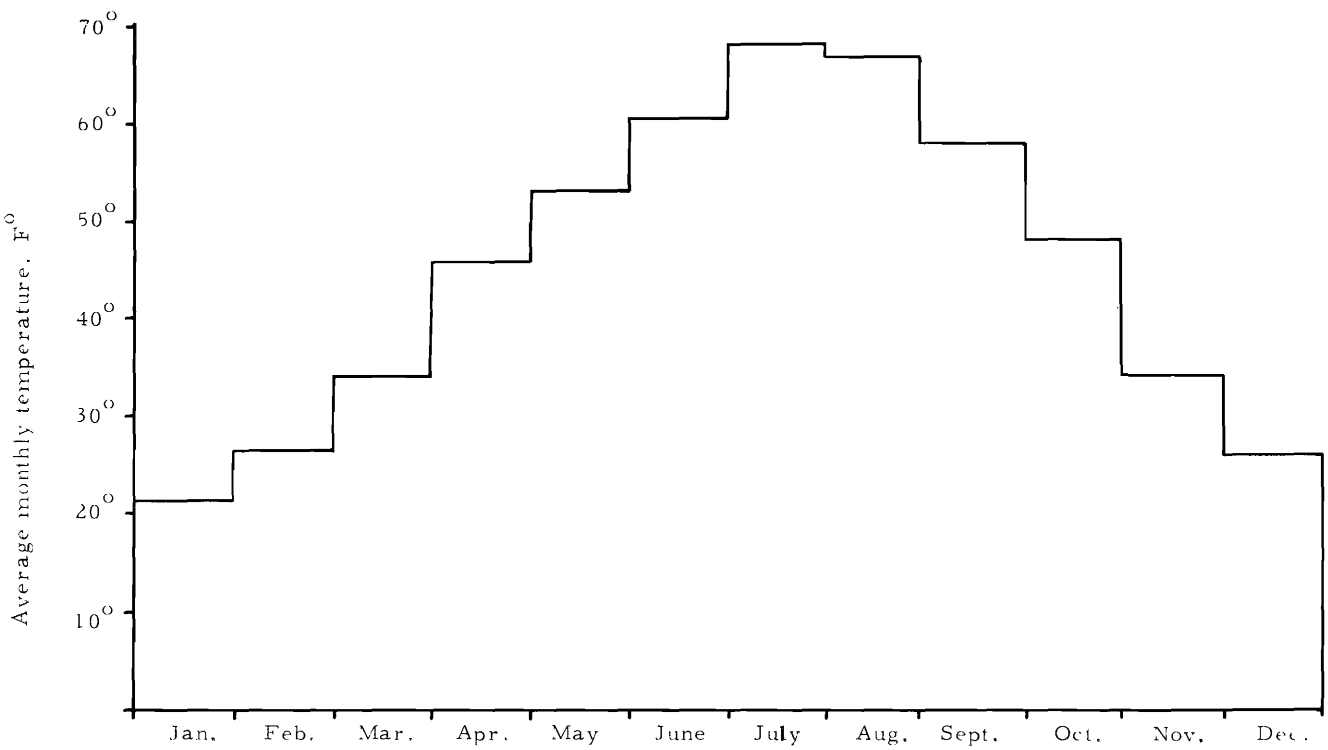

Figure 1.5. Average monthly temperature for the irrigated crop land of Cache Valley (1931-1965).

CHAPTER II

SYSTEMS MODELING

Modeling Techniques

Management of water-resource systems, as with other types of public operations, deals with techniques of decision making. Models used to study the management of such systems need to consider both the physical processes and the economic implications involved in all stages of the prototype. The problem of designing a model is to reproduce or represent in space and time the physical and economic processes associated with the system. To this model it is possible to apply the physical inputs, the constraints, and the theoretical apparatus of production and allocation economics. In order to choose from alternative courses of action, an objective or set of objectives must be specified and developed as a guide to optimal management.

In recent years hydrologists have attempted to develop suitable mathematical models to represent the hydrologic system. Considerable attention has been given to the development of models of complex water resource systems. As already indicated, initial steps in developing a mathematical model of both the physical and the economic flow systems of a hydrologic unit were undertaken approximately 10 years ago under the Harvard water resources program (Maass et al., 1962). In general, the models commonly applied to water resource systems design fall into two broad categories: Physical models and mathematical models.

Physical models

Physical models are normally scale reproductions of the prototype but may be distorted in the horizontal or vertical dimension. Measurements or observations are made by subjecting the model to conditions similar to those confronted by the prototype. In the first period of physical model investigations, model reproduction based on the similarity of hydraulic factors was considered satisfactory. At a later stage fundamental laws governing transporation of solid materials were considered, and still further development led to the consideration of morphological characteristics of the water courses. Such models were used to test the performance of various hydraulic structures, flood and erosion control measures, and sediment transport problems.

In recent years there has been a renewed interest in the use of small-scale artifical drainage basins for studying the rainfall-runoff process in the laboratory. Some researchers (Grace and Eagleson, 1965) have concluded that strict dynamic similarity of a physical watershed model could be accomplished only for small impervious watersheds not exceeding the size of one acre. If the problems of economics and other associated complex factors are also to be directly considered in the management of a water resource system, it may be concluded that physical models offer few practical choices. For problems of this nature, it is necessary to consider another type of modeling technique.

Mathematical models

A dynamic system, such as a water resource system, is characterized by three basic components: Input, storage, and output. These three components may be related by one or more mathematical formulation. Interdependent relationships exist among individual physical, economic, and social system components. A model, including the interdependent relationships, can be conveniently developed with the river subbasin as the basic space unit of study.

In recent years, the search for suitable models of the water resource systems has led to the development of two basic approaches or techniques: Analytical models and simulation models. Both kinds of models represent the physical system with quantitative inputs and outputs determined by mathematical relationships.

Analytical models. An analytical model is a set of equations intended to be solved for optimization of the outputs in terms of a specified objective function. For example, the most suitable combination of factors, such as cropping patterns and water use, might be sought with the objective of optimizing net income. Optimization is accomplished with the aid of standard methods of algebra and calculus.

Analytical models that yield optimal solutions have practical limitations when applied to complex water resource systems. Solution of a system of equations by analytical methods usually requires both sectional modeling and simplifying assumptions.

Simulation models. A generally accepted solution to the problem of engineering analysis is the adoption of the principles of simulation wherein a physical system is modeled in some practical manner. Through simulation methods, nonlinear, dynamic models of complex systems are entirely possible. For this reason, simulation is frequently the only practical procedure available for the analysis of water resource systems even though it does not directly yield the optimum solution.

The advantages of simulation include:

1. Insight is provided into the make-up and operation of the system being modeled and the relative importance of the various components within the system.
2. The system can be nondestructively tested, which is of particular interest in the design of large dams and flood control measures in a river basin.
3. Proposed modifications of existing systems can be tested for performance prior to installation.
4. Various system designs may be studied at minimum expense, thus avoiding the selection of unsatisfactory alternatives.

As already indicated, an important limitation to simulation is that it does not along five optimal answers to design problems. A single simulation run with a unique set of values for the design variables provides an estimate of the system performance. In effect it involves exploration of an n-dimensional response surface in which the results of any single trial with a unique set of the design variables constitutes a single point on this surface.

Simulating a water resource system involves building a model that represents all of the inherent system characteristics while predicting responses of the system. The model usually includes some nonmathematical or logical processes. If desired, systems can be analyzed in terms of their dynamic response to parameter variation.

No reference was found in the literature to studies wherein the hydrologic and economic flow systems are effectively modeled and linked on a deterministic basis such that the interactions between the two systems can be examined and considered by the model. The study reported herein describes an initial attempt to bridge this gap in water resource system management techniques. The problem is simplified by assuming a system which involves only agricultural production.

Simulation Methods

Simulation can be performed by active and passive analog systems or active digital systems. Passive analog models have been applied to investigations of groundwater phenomena for many years. Active simulation is a relatively new development and is performed by the analog or digital computer solution of mathematical relationships which describe the system. Simulation in this study was performed by both analog and digital computer solution of the system equations.

CHAPTER III

THE HYDROLOGIC MODEL

Formulation of a Hydrologic Model

Model requirements

To meet the fundamental requirements of a computer model of a hydrologic system, it must be demonstrated that:

1. It simulates on a continuous basis all important processes and relationships within the system it represents.
2. It is nonunique with respect to space. This implies that it can be applied easily to different geographic areas with existing hydrologic data.
3. It is capable of answering questions concerning perturbations in the system or of accurately predicting outputs resulting from varying input and process parameters.

The general research philosophy involved in the development of a simulation model of a dynamic system, such as a hydrologic unit, is shown by the flow diagram of Figure 3.1. In addition to predicting system responses to particular input functions and parameter changes, the process of model development provides for improvement of system relationships.

The conceptual model

The hydrologic model utilized in this study is a modified version of that developed in earlier studies involving the computer simulation of a complete watershed unit (Riley et al., 1966 and 1967). Simplification was achieved by including only the valley bottom lands.

The basis of the hydrologic model is a fundamental and logical mathematical representation of the various hydrologic processes and routing functions. These physical processes are not specific to any particular geography, but rather are applicable to any hydrologic unit, including all of the subbasins located within the Bear River basin. Experimental and analytical results were used whenever possible to assist in testing and establishing some of the mathematical relationships included within the model. Under a model verification procedure, equation constants are established which calibrate or fit the model for a particular drainage area. Average values of hydrologic quantities needed for model verification were estimated from available data, by statistical correlation techniques, and through verification of the model.

A flow diagram of the hydrologic system is shown by Figure 3.2. As this flow chart indicates, the total input to a subbasin is the combination of surface and subsurface inflows of water obtained by summing river and tributary inflows, precipitation, groundwater, and imports from other subbasins. Depletions from the subbasins occur through evapotranspiration, municipal and industrial consumption, exports, plus surface and subsurface outflows. As water passes through this system, storage changes occur on the land surface, in the soil moisture zone, in the groundwater zone, and in the stream channels. These changes occur rapidly in surface locations and more slowly in the subsurface zones. Subsurface flows undergo various time delays as they move through the system. Each parameter and process depicted by Figure 3.2 is discussed in some detail in the following sections.

The hydrologic balance

A dynamic system consists of three basic components, namely the medium or media acted upon, a set of constraints, and an energy supply or driving force. In a hydrologic system, water in any one of its three physical states is the medium of interest. The constraints are applied by the physical nature of the hydrologic basin, and the driving forces are supplied by direct solar energy, gravity, and capillary potential fields. The various functions and operations of the different parts of the system are interrelated by the concepts of continuity of mass and momentum. Unless relatively high velocities are encountered, such as in channel flow, the effects of momentum are negligible, and the continuity of mass becomes the only link between the various processes within the system.

Continuity of mass is expressed by the general equation:

$$\text{Output} = \text{Input} \pm \text{Change in storage}$$

A hydrologic balance is the application of this equation to achieve an accounting of physical, hydrologic measurements within a particular unit. Through this means and the application of appropriate translation or routing functions, it is possible to predict the movement of water within a system in terms of its occurrence in space and time.

In the course of model development, each of the system processes must be described mathematically as completely as possible and related to the other processes as described in the above flow chart. Each box and connecting line in the flow chart is represented by a mathematical expression in the model.

Time and space increments

Practical data limitations and problem constraints require that increments of time and space be considered during model design. Data, such as temperature and precipitation readings, are usually available as point measurements in terms of time and space; and integration in both dimensions is usually accomplished by the method of finite increments.

The complexity of a model designed to represent a hydrologic system largely depends upon the magnitude of the time and spatial increments utilized in the model. In particular, when large increments are applied, the scale magnitude is such that the phenomena which change over relatively small increments of space and time are masked. For instance, on a monthly time increment, interception rates and changing snowpack temperatures are neglected. In addition, the time increment chosen might coincide with the period of cyclic changes in certain hydrologic phenomena. In this event net changes in these phenomena during the time interval are usually negligible. For example, on an annual basis, storage changes within a hydrologic system are often insignificant, whereas on a monthly basis, the magnitude of these changes is frequently appreciable and needs to be considered. As time and spatial increments decrease, improved definition of the hydrologic processes is required. No longer can short-term transient effects or appreciable variations in space be neglected, and the mathematical model, therefore, becomes increasingly complex with an accompanying increase in the requirments of computer capacity and capability.

For the study of the Cache Valley subbasin discussed in this report, a monthly time increment and large space unit (subbasin) were adopted. Selection of the subbasin was based on hydrologic boundaries and points of data collection. It was felt that the selection of the subbasin and the monthly time increment could satisfy the requirements of a general hydro-economic model.

System Processes

Surface inflows

The basic inflow or input of water into any hydrologic system originates as a form of precipitation.

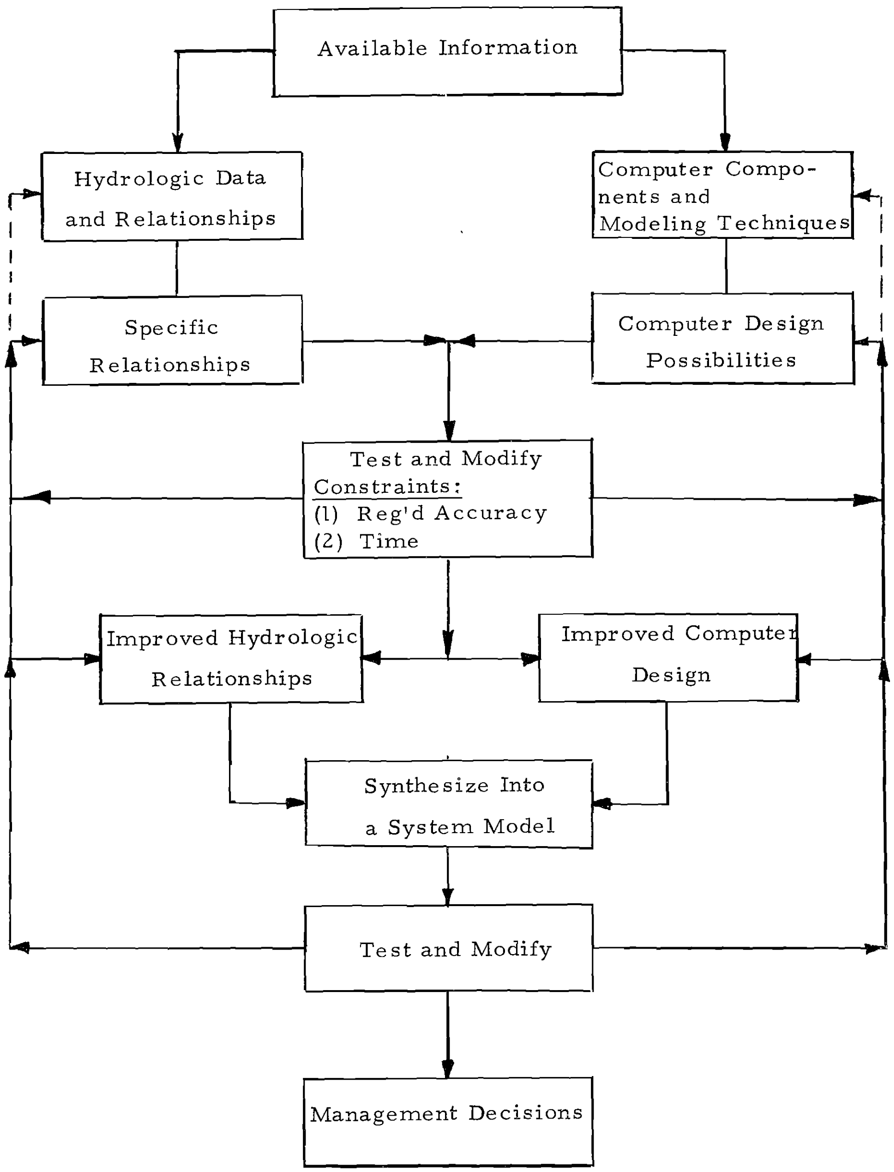

Figure 3.1. Development process of a hydrologic model.

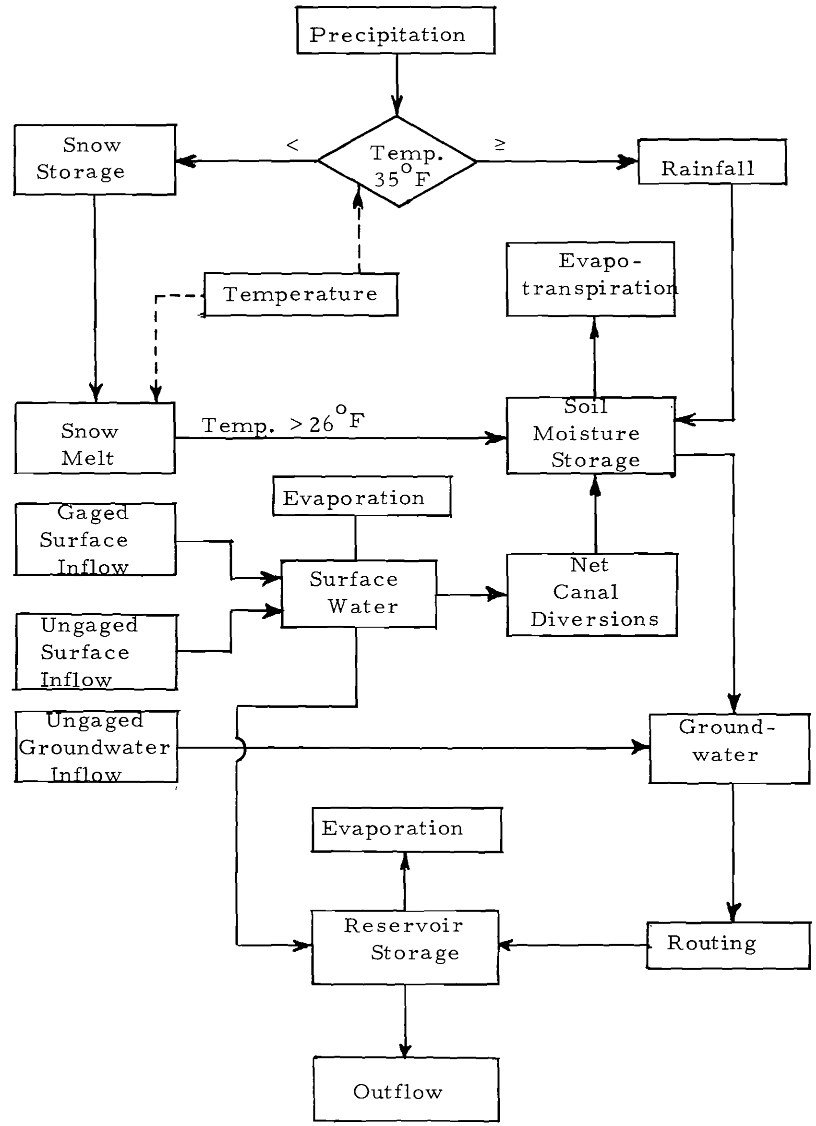

Figure 3.2. Flow diagram for a typical hydrologic model using large time increments.

However, for simulation models of valley floor areas, direct precipitation input to the system is greatly overshadowed by river and tributary inflows.

Streamflow is defined as that portion of the precipitation which appears in streams and rivers as the net or residual flow collected from all or a portion of a watershed. Artificial diversions and regulatory action in lakes and reservoirs affect the regimes of every stream within Cache Valley.

The surface water inflow component consists of flow traveling over the ground surface and through channels to enter a stream. At the stream, surface runoff usually combines with other flow components to form the total surface runoff hydrograph. Within the runoff cycle (Chow, 1964), surface runoff begins to occur when the capacities of vegetative interception, infiltration, and surface runoff are satisfied. Small subbasins have different runoff characteristics than large watersheds, and the characteristics peculiar to each subbasin must be evaluated on an individual basis.

For each subbasin, a limiting rate of surface runoff exists for any particular time period. Surface runoff is assumed to occur when the threshold or limiting rate of surf- ce water supply, consisting of snowmelt, rainfall, canal diversions, or any combination of these, is exceeded.

This concept of surface runoff is particularly important when precipitation is considered as the initial water input to the watershed. Riley et al. (1966) indicate that for particular conditions there exists a limiting or threshold rate of surface supply, R_{tr}, at which surface runoff, S_r, begins to occur. This relationship can be written:

$$S_{wr} = W_{gr} - R_{tr}, \quad (S_{wr} \geq 0) \quad . \quad . \quad . \quad (3.1)$$

in which

S_{wr} = rate of surface runoff during a particular time

W_{gr} = rate at which water is available at the soil surface

R_{tr} = limiting or threshold rate of surface water supply at which surface runoff begins to occur

In this study only the valley bottom lands are considered in the model, and it is assumed that no surface runoff from precipitation occurs from these relatively flat areas. Under this assumption, the rate at which precipitation is available at the soil surface at no time exceeds the threshold rate for surface runoff to occur. Thus,

$$S_{wr} = 0, \quad (W_{gr} \leq R_{tr}) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3.2)$$

The model does provide for surface runoff from agricultural lands due to irrigation application rates which exceed soil infiltration rates. This runoff quantity constitutes a portion of the irrigation return flow.

Surface runoff from the surrounding watershed areas is concentrated in stream channels, and therefore enters the model (valley bottom) as tributary flow. That part of the inflow rate which is measured or gaged is designated as $Q_{is}(m)$.

Unmeasured surface inflows to the model are estimated by a correlation technique which considers three hydrologic parameters, namely a gaged tributary inflow rate, precipitation rate, and snowmelt rate. Thus, in functional form:

$$Q_{is}(u) = \int [q_{is}(m), P_r, W_{sr}] \quad . \quad . \quad . \quad (3.3)$$

in which

$Q_{is}(u)$ = estimated rate of unmeasured surface inflow

$q_{is}(m)$ = measured rate of surface inflow from a particular tributary area

P_r = gaged precipitation rate in the form of rain on the valley floor

W_{sr} = estimated snowmelt rate in terms of water equivalent from the plant and surrounding environment such as adjacent soil surfaces. Potential evapotranspiration is defined as that rate of consumptive use by actively growing plants which occurs under conditions of complete crop cover and non-limiting soil moisture supply.

The evapotranspiration process depends upon many interrelated factors whose individual effects are difficult to determine. Included among these factors are type and density of crop, soil moisture supply, soil salinity, and climate. Climatological parameters usually considered to influence evapotranspiration rates are precipitation, temperature, daylight hours, solar radiation, humidity, wind velocity, cloud cover, and length of growing season. Numerous relationships have been developed for estimating the potential evapotranspiration rate.

Perhaps one of the most universally applied evapotranspiration equations is that proposed by Blaney and Criddle (1950). This equation is written as:

$$U = kf \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (3.19)$$

in which

U = monthly crop potential consumptive use in inches

k = monthly coefficient which varies with type of crop

f = monthly consumptive use factor and is given by the following equation:

$$f = \frac{tp}{100} \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (3.20)$$

in which

t = mean monthly temperature in ^{o}F

p = monthly percentage of daylight hours of the year

A modification of the Blaney-Criddle formula was proposed by Phelan (1962), wherein the monthly coefficient, k, is subdivided into two parts, a crop coefficient, k_c, and a temperature coefficient, k_t. The relationships describing k_t is an empirical one, depending upon only temperature, and is expressed as:

$$k_t = (0.0173\ T_a - 0.314) \quad . \ . \ . \ . \ . \quad (3.21)$$

where T_a is the mean monthly temperature in ^{o}F. The crop coefficient, k_c, is basically a function of the physiology and stage of growth of the crop. Typical curves which indicate values of k_c throughout the growth cycle of particular crops are shown by Figure 3.3 which is for alfalfa. Similar k_c curves are available for many agriculture crops (U. S. Soil Conservation Service, 1964).

Thus, the modified Blaney-Criddle equation for estimating potential evapotranspiration rates is written:

$$ET_{cr} = k_c\, k_t \frac{T_a p}{100} \quad . \ . \ . \ . \ . \ . \ . \ . \quad (3.22)$$

Because of its simplicity, low data requirements (only surface air temperature is needed), and applicability to the irrigated areas of the Western United States, Equation 3.22 was adopted for this study model. Since the time increment selected for use was one month, the variables on the right of Equation 3.22 represent mean monthly values, although these parameters could be expressed as continuous functions instead of the indicated step functions. Thus, Equation 3.22 estimates the mean potential evapotranspiration rate during each month.

The growing season was assumed to begin and end when the mean monthly air temperature reached a value of $32^{o}F$. Evapotranspiration losses from the agriculture area during the non-cropping season were estimated from Equation 3.22. For many crops it was necessary to extend the k_c curves to include the non-growing season (West, 1959). Because the k_c curve for grass pasture seems to represent a reasonable set of values for native vegetation (Riley et al., 1967), this curve was used as a guide in the development of a similar k_c curve for phreatophytes.

Effects of soil moisture on evapotranspiration. As the moisture content of a soil is reduced by evapotranspiration, the moisture tension which plants must overcome to obtain sufficient water for growth is increased. It is generally conceded that some reduction in the evapotranspiration rate occurs as the available quantity of water decreases in the plant root zone. Recent studies by the U. S. Salinity Laboratory in California (Gardner and Ehlig, 1963) indicate that transpiration occurs at the full potential rate through approximately the first one-third of the available soil moisture range, and that thereafter the actual evapotranspiration rate lags the potential rate. When this critical point in the available moisture range is reached, the plants begin to wilt because soil moisture becomes a limiting factor. Thereafter, an essentially linear relationship exists between the available soil moisture and the actual transpiration rate. The actual evapotranspiration rate is expressed by Riley et al. (1966) in accordance with the end conditions which accompany the two following equations:

$$ET_r = ET_{cr}, \; [M_{es} < M_s(t) \leq M_{cs}] \quad . \quad (3.23)$$

and

$$ET_r = ET_{cr} \frac{M_s(t)}{M_{es}}, \; (0 \leq M_s(t) \leq M_{es}) \quad (3.24)$$

in which

ET_r = actual evapotranspiration rate

ET_{cr} = potential evapotranspiration rate

M_{es} = limiting or threshold content of available water within the root zone below which the actual becomes less than the potential evapotranspiration rate

$M_s(t)$ = quantity of water available for plant consumption which is stored in the root zone at any instant of time

M_{cs} = root zone storage capacity of water available to plants

Because they are differential with respect to time, both Equations 3.23 and 3.24 are easily programmed on the computer. In the integrated form Equation 3.24 appears as:

$$M_s(2) = M_s(1) \exp \left[-\frac{ET_{cr}}{M_{es}} (t_2 - t_1) \right] \quad . \quad (3.25)$$

in which $M_s(1)$ and $M_s(2)$ are the soil moisture storage values at time t_1 and t_2, respectively. Hence, when conditions are such that the available soil moisture storage reduces the potential evapotranspiration rate, the actual consumptive use rate can be expressed by combining Equations 3.22 and 3.24 to read:

$$ET_r = \frac{M_s}{M_{es}} k_c k_t \frac{T_a p}{100} \quad . \; . \; . \; . \; . \; . \quad (3.26)$$

Equation 3.26 is programmed on the computer to estimate the actual evapotranspiration rate. The equation reduces to Equation 3.22 when $M_s > M_{es}$ so that $ET_r = ET_{cr}$.

Effects of slope and elevation on evapotranspiration. In that they affect the available energy supply, land slope (degree and aspect) and elevation influence the evapotranspiration process. Riley and Chadwick (1967) considered the effects of slope by introducing a radiation index parameter. These same authors also introduced an elevation correction into Equation 3.26. This adjustment is necessary for watershed studies since surface air temperature becomes a less reliable index of the available energy with increased elevation above the valley floor. However, because the model of this study was confined to the relatively flat valley floor areas, the effect of both slope and elevation on the evapotranspiration rate was neglected.

Deep percolation

The final independent term, G_r, of Equation

3.16 represents the rate of deep percolation. Percolation is simply the movement of water through the soil. Deep percolation is defined as water movement through the soil from the plant root zone to the underlying groundwater basin. The dominant potential forces causing water to percolate downward from the plant root zone are gravity and capillary. Water is removed quickly by gravity from a saturated soil under normal drainage conditions. Thus, the rate of deep percolation, G_r, is most rapid immediately after irrigation when the gravity force dominates, and decreases constantly, continuing at slower rates through the unsaturated conditions. Because the capillary potential applies through all moisture regimes, deep percolation continues, though at low rates, even when the moisture content of the soil is less than field capacity (Willardson and Pope, 1963).

Because of a lack of data in the study area regarding deep percolation rates in the unsaturated state, and in order to simplify the model, the assumption was made that deep percolation occurs only when the available soil moisture is at its capacity level. In most cases, this assumption causes only slight deviation from prototype conditions. Thus, for this model, the deep percolation rate is expressed as:

$$G_r = F_r - ET_{cr}, \ [\ M_s(t) = M_{cs}] \quad . \ . \ (3.27)$$

$$G_r = 0, \ [\ M_s(t) < M_{cs}]. \quad . \ . \ . \ . \ . \ (3.28)$$

in which all terms are as previously defined.

River outflow

Using the continuity of mass principle, the hydrologic balance is maintained by properly accounting for the quantities of flow at various points within the system. The appropriate translation or routing of inflow water through the system in relation to the chronological abstractions and additions occurring in space and time concentrates the water at the outlet point as both surface and subsurface outflow. As mentioned earlier, active network delays on the computer simulate the long transport time necessary for groundwater inflows and deep percolating water to be routed to the outflow gaging station.

Thus, the total rate of water outflow from a subbasin is obtained through the summation of various quantities as follows:

$$Q_o = Q_{is} - W_{tr} + OF_r + Q_{ob} - Q_e \quad . \ . \quad (3.29)$$

in which

Q_o = total rate of outflow from the system

Q_{is} = rate of total surface inflow to the subbasin including both measured and unmeasured flows

W_{tr} = total rate at which water is diverted from the stream or reservoir

OF_r = total of overland flow and interflow rates

Q_{ob} = rate of outflow from the groundwater basin of routed deep percolating waters and subsurface inflows to the subbasins

Q_e = rate of water diversions from surface sources for use outside the boundaries of the subbasin. Exports to other drainage basins fall within this category.

If subbasins are selected such that there exists no flow of subsurface water past the gaged outflow point, the hydrograph of surface outflow, Q_{so}, is given by Equation 3.29. This situation is assumed to exist at reservoir sites within the basin because of construction measures taken to eliminate subsurface flows under the dams which create the reservoir. For this reason, whenever possible, subbasins are terminated at the outfall of a reservoir. These sites enable a check on groundwater inflow rates to the subbasin as predicted from verification studies involving models for one or more upstream subbasins.

For many subbasins the termination or outlet point is taken at a Geological Survey gaging station, and in some of these cases groundwater flow occurs in the streambed alluvium beneath the surface channel. For these basins, the total system outflow can be written as:

$$Q_{to} = Q_{so} + Q_{go} \quad . \ . \ . \ . \ . \ . \ . \ . \ (3.30)$$

in which

Q_{so} = rate of surface outflow from the subbasin

Q_{go} = rate of subsurface or groundwater outflow from the subbasin

Surface outflow rates, Q_{so}, can be compared to the recorded values, but subsurface outflow rates, Q_{go}, are unmeasured and must be predicted or estimated. It can be assumed that the subsurface outflow rates are directly proportional to the total outflow rates, and Q_{go} is therefore estimated by the following relationship:

$$Q_{go} = k_d \, Q_o \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ (3.31)$$

in which

k_d = a coefficient determined by model verification representing the percentage of total outflow which leaves the basin as subsurface flow

Because of storage and permeability effects, fluctuations in groundwater flow rates tend to be much less extreme than in the case of surface flows. The value of k_d in Equation 3.31 is, therefore, not maintained as a constant, but is expressed as an inverse function of the surface flow rate, Q_{so}. During the spring runoff period, for example, the predicted increases in subsurface outflow rate, Q_{go}, from Equation 3.31 are considerably less extreme than the increase in observed or computer surface flow rate, Q_{so}. Relationships expressing k_d as a function of Q_{so} can be developed for any subbasin through the model verification process. However, since the outflow boundary coincided with the location of a dam; the ungaged groundwater outflow rate was assumed negligible.

CHAPTER IV

ECONOMIC SYSTEM

The theory involved in the formation of the economic model for this study does not attempt to describe the agricultural economic system in detail. It does, however, attempt to predict the average economic conditions which can be expected to occur under a given set of conditions and constraints. The economic model described here, in conjunction with the hydrologic model, provides a means of establishing guides for planning and developing existing land and water resources. The economic system includes the crops produced on irrigated farm land and their relationship to the hydrologic system, but does not directly consider livestock or municipal uses. A simplified flow diagram of the agricultural economic unit is shown in Figure 4.1. The basic economic unit of the study may be an individual farm or a river subbasin.

The economic returns to agricultural crops are basically related to the yield of the corresponding crops. Higher yields are associated with higher gross returns to the farm, higher costs, and normally higher net returns. The connecting link between the hydrologic and economic flow systems of an agricultural complex is dependent upon such factors as water availability, water requirements, and production per unit of water consumed. However, water is only one of many factors which influence production in agriculture. Production is also a function of management, capital, labor, crop variety, soil type, and soil fertility. By maintaining these other factors at relatively constant levels, it is possible to estimate production (yield) as a function of water consumed.

Hydrologic Contribution

The hydrologic system is related indirectly to the economic system by the amount of water which is applied to the crops, both artificially and naturally, to sustain crop growth. Yield is more directly a result of water use than application rates.

Some sources (Wilson, 1967; Johnson, 1967; Miller, 1965; and Widstoe and Merrill, 1912) have used the total water applied to crops as an estimate of crop yield. This approach is usually adopted because adequate data on consumptive use of water by crops are not available. An error is introduced by consideration of total water applied due to the great variation in application efficiency and storage capacity of the soils from one farm unit to another.

The approach, suggested by Stewart and Hagan (1968), that the crop yield is a nonlinear function of evapotranspiration during the growing season was adopted for this study. Seasonal evapotranspiration, then, is the hydrologic contribution to the estimation of crop yield.

Economic Unit

Economics of agricultural crops on a total valley basis are assumed to be related to the available moisture. The economic unit deals with the agricultural crop, production, marketing, and the related costs and benefits within Cache Valley. Since the irrigated land of Cache Valley is included in the study area for the model, there is a direct correspondence between the hydrologic and economic systems.

Crop cost functions

There are fixed and variable costs associated with the production of each crop. Fixed costs (also called overhead costs) do not vary with the level of output during the time period under study, normally one year. Real estate taxes are an example of fixed costs of production because they will not change with

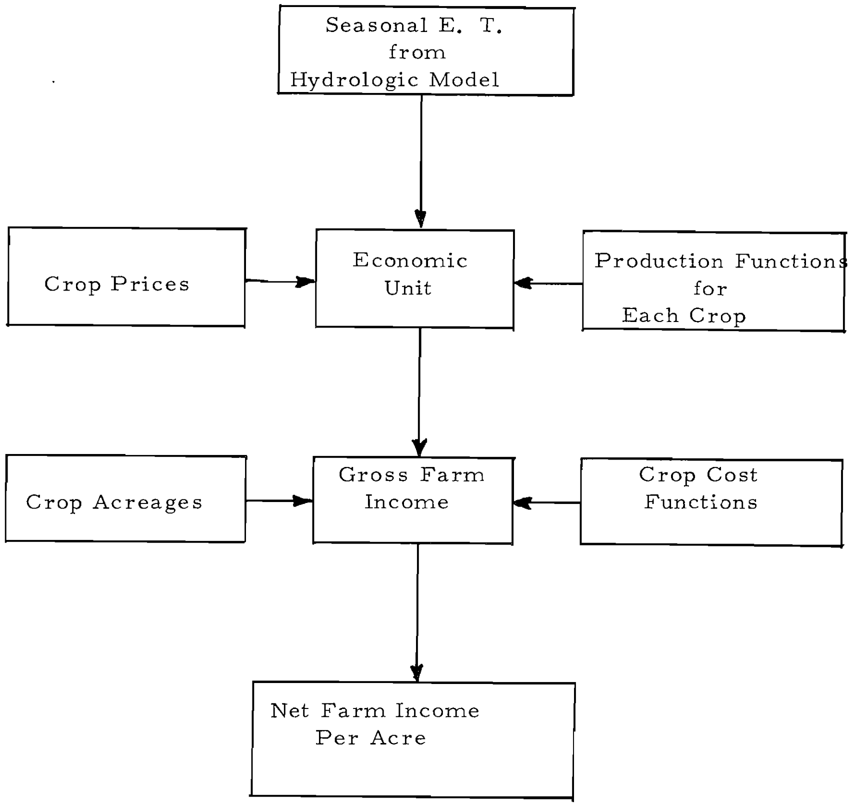

Figure 4. 1. Flow diagram of economic system.

the level of farm production in any particular year.

Variable costs, on the other hand, vary with the level of output. An example of variable cost is the cost of fertilizers. If more fertilizer is applied to increase the crop yield, then the cost of fertilizer will increase. Variable costs may also change due to scale economies such as higher yields related to efficiency of large farm units. Average costs decline as the scale of operations increase. This is due primarily to the use of larger and more specialized machinery and buildings. Marginal costs are the change in total costs associated with an incremental change of inputs. The cost data used for this study were taken from a report by Hiskey (1968).

Table 4. 1 may be referred to for the costs associated with alfalfa production. The costs associated with other crops appear in Appendix C. The capital cost associated with agricultural production for this study was included as a fixed cost (Table 4. 1(a)). It was assumed that there would be an interest due on money borrowed, or an opportunity cost associated with money invested in land and other factors of production.

The cost of production has been itemized in Table 4. 1(a). For example, requirements for a farm tractor are expected to be 1. 8 hours per acre at a cost of $1. 69 per hour on a 60 acre alfalfa field. Table 4. 1(b) indicates the total costs per acre and returns per acre that can be expected at various

Table 4.1(a). Typical costs of alfalfa production.[1]

	Quantity of Input	Cost of Input	Cost Farm	Cost Acre
Tractor	1.8 hrs/ac.	1.69/hr.	182.40	3.04
Cultivating 2X	60 ac.	.15/ac.	18.00	.30
Swather 3X	60 ac.	2.42/ac.	435.60	7.26
Baler	270 T.	1.22/T.	329.40	5.49
Fertilizer Spreader	60 ac.	.35/ac.	21.00	.35
Ditcher	60 ac.	.23/ac.	13.80	.23
Fertilizer	60 ac.	2.00/ac.	120.00	2.00
Sprayer - (Hired)	60 ac.	2.50/ac.	150.00	2.50
Interest on Capital	60 ac.	6% on $500	1800.00	30.00
Taxes	60 ac.	4.00/ac.	240.00	4.00
Water	60 ac.	6.65/ac.	399.00	6.16
Interest on Operating Capital	60 ac.	.35/ac.	21.00	.35
Seed		.83/ac.		.83
Pickup and Auto Cost				5.25
TOTAL COST				67.76

[1] Based on a cropped area of 60 acres with an assumed yield of 4.5 tons per acre.

Table 4.1(b). Estimated net return for alfalfa production at various levels of yield.

Yield (tons/acre)	6	5	4.5	4	3.5	3	2.5	2	1
Hay $21/Ton	126.00	105.00	94.50	84.00	73.50	63.00	52.50	42.00	21.00
Pasture	6.00	5.00	4.50	4.50	4.50	4.00	4.00	3.00	--
Gross Income	132.00	110.00	99.00	88.50	78.00	67.00	56.50	45.00	21.00
Variable Expenses	6 T.	5 T.	4.5 T.	4 T.	3.5 T.	3 T.	2.5 T.	2 T.	1 T.
Water	6.16	6.16	6.16	5.28	3.96	2.64	2.64	1.32	0
Fertilizer	2.00	2.00	2.00	2.00	2.00	1.50	1.00	--	--
Baling	7.32	6.10	5.49	4.88	4.27	3.66	3.05	2.44	1.22
Swathing	7.26	7.26	7.26	7.26	7.26	4.84	4.84	2.42	2.42
Spray	2.50	2.50	2.50	2.50	2.50	2.50	2.50	--	--
Tractor	4.00	3.35	3.04	2.70	2.35	2.02	1.70	1.36	.70
Total	29.24	27.37	26.45	24.62	22.34	17.16	15.73	7.54	4.34
	67.76	67.76	67.76	67.76	67.76	67.76	67.76	67.76	67.76
	+ 2.79	+ .92	.00	- 1.83	- 4.11	- 9.29	-11.08	-18.91	-22.11
Gross Costs	70.55	68.68	67.76	65.93	63.65	58.47	56.68	48.85	45.65
Gross Income	132.00	110.00	99.00	88.50	78.00	67.00	56.50	45.00	21.00
Gross Costs	70.55	68.68	67.76	65.93	63.65	58.47	56.68	48.85	45.65
Net return to labor and mgt.	61.45	41.32	31.24	22.57	14.35	8.53	-.18	-3.85	-24.65

levels of production.

Production cost data are plotted in Figure 4.2 and Appendix C as quadratic curves which represent the costs associated with various levels of farm production.

Crop market prices

The value of agricultural production is measured by the market prices of the crops produced. The prices used in this study are averages of the local 1968 prices. This model was assumed to simulate only the short-run economics, and demand was assumed to have no effect on the fixed prices. The values used in this study for market prices of various crops are listed in Table 4.2. If long-run conditions were studied, variable prices would be introduced according to a recorded or predicted schedule.

Gross returns for each crop were found by multiplying the crop yield per acre, crop area in acres, and the market price of the crop. All crops produced were assumed to be sold at the time of harvest at the current market prices.

Economic Evaluation Function

Once the physical productivity of water is established for each crop, the economic productivity of each crop can be determined by attaching monetary values to the output and resource inputs. Net returns are then determined by the model from the production function of each crop and the cost associated with each crop production process.

In any particular year, farmers report a wide range in yields of crops per acre. Many factors are responsible for this situation. Some farmers are more skilled than others in using identical production techniques. There is also a substantial variation in the inherent production capacity of the land from one farm to another.

In economic analysis, the benefits and costs are expressed in monetary terms on an annual basis for each crop. The annual gross benefits per acre less the total annual costs per acre is the annual net farm income per acre of production. The total net farm income is the sum of the products of the total area under each crop and the net farm income per acre for each crop. Mathematically, the total net farm income is expressed by:

$$NI = \sum_{i=1}^{n} (Y_i \cdot P_i \cdot A_i) - \sum_{i=1}^{n} [(O_i + F_i + I_i) A_i] \qquad \ldots\ldots\ldots\ldots (4.1)$$

in which

NI = net farm income

Y_i = annual yield per acre for crop (i)

P_i = price per unit of yield for crop (i)

O_i = annual operating costs per acre for crop (i)

F_i = annual fixed costs per acre for crop (i)

I_i = annual interest costs on investment per acre for crop (i)

A_i = number of acres of crop (i)

The total net farm income is the measure of actual profit to the farmer and, for different levels of water use, is an essential economic measure of productivity in determining the most efficient use of the available water supply. In order to maximize net return, the farmer attempts to find the most profitable combination of variable factors and fixed factors involved in the operation. For a given level of technology and fixed production factors, the farmer varies those inputs that can be changed in order to equate marginal revenue and marginal cost. If the farmer takes each crop price as determined by the market, since the farmer is a price-taker, and equates marginal revenue with marginal cost for each crop, he is maximizing the net return from the farm (Wilcox and Cochrane, 1960).

One might reason that, when a farmer has found a particular cropping pattern which maximizes his net returns under the given conditions, he has found a permanent solution. But this is not so, mainly because the "given conditions" are

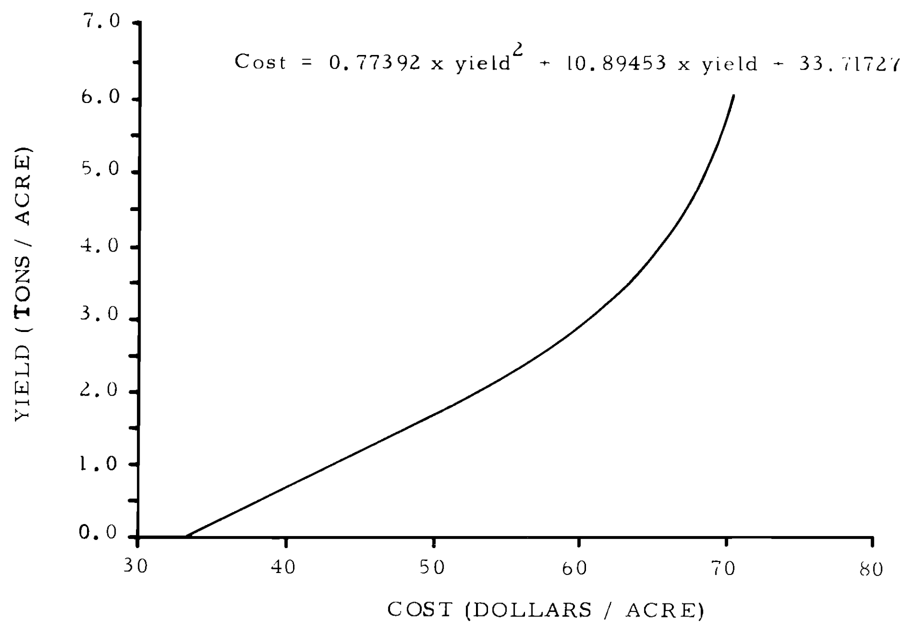

Figure 4.2. Cost--yield relationship for alfalfa.

constantly changing. Changes may occur for the following reasons:

1. Changes in a natural resource such as water supply.
2. Changes in consumer supply or demand, and therefore prices.
3. Changes in transportation to market costs, which makes areas more distant from markets either more or less competitive.
4. Changes in infestations of crops by pests and diseases.
5. Changes in farm machinery.
6. Changes in seed varieties.

Economic System

Inputs

The inputs to the economic model are:

1. Seasonal evapotranspiration from each crop (as an index of crop yield).
2. Production cost-yield relationships.
3. Market prices of the crop yields which are considered constant for one year.

Outputs

The output values from the economic model are dependent upon both the input functions and the constraints associated with the physical and economic system. Output values include several important indexes which indicate the success or failure or particular farm management policies. Typical of these indexes are:

1. Crop yield per acre.
2. Gross returns per acre.
3. Actual costs incurred per acre.
4. Net returns per acre.

Table 4.2. Market prices for various agricultural crops.

Crop (unit)	Sugar beets (ton)	Corn (ton)	Small Grains (bushels)	Al-falfa (ton)	Pas-ture (AUM)
Market Price ($/unit)	16.60	7.00	1.05	21.00	5.50

CHAPTER V

LINKING THE HYDROLOGIC AND ECONOMIC SYSTEMS

In the development of a hydrologic-economic model, it is necessary to give careful consideration to the nature of the relationships between hydrologic and economic systems. A hydrologic-economic model is an integrated unit of the physical processes and quantitative economic phenomena. Since a strong interrelationship exists between the physical and economic systems, it is necessary to develop a unified treatment in the synthesis of the model.

Figure 5.1 presents the basic components of the hydrologic and economic systems and the relationships existing between them. The various components of these systems are discussed in previous chapters.

The link between the hydrologic and economic systems is the production function for each crop. A production function is the relationship between the crop yield and the seasonal evapotranspiration of the crop, for the assumed constant or near constant levels of fertility, management, and other conditions.

Seasonal evapotranspiration is the hydrologic input to the production function. The monthly value of the evapotranspiration coefficient k_c and the monthly average temperature determine the monthly evapotranspiration. If the value of k_c is greater than 0.26 the evapotranspiration is accumulated for that month and crop. If it is equal to or less than 0.26, the evapotranspiration is assumed to

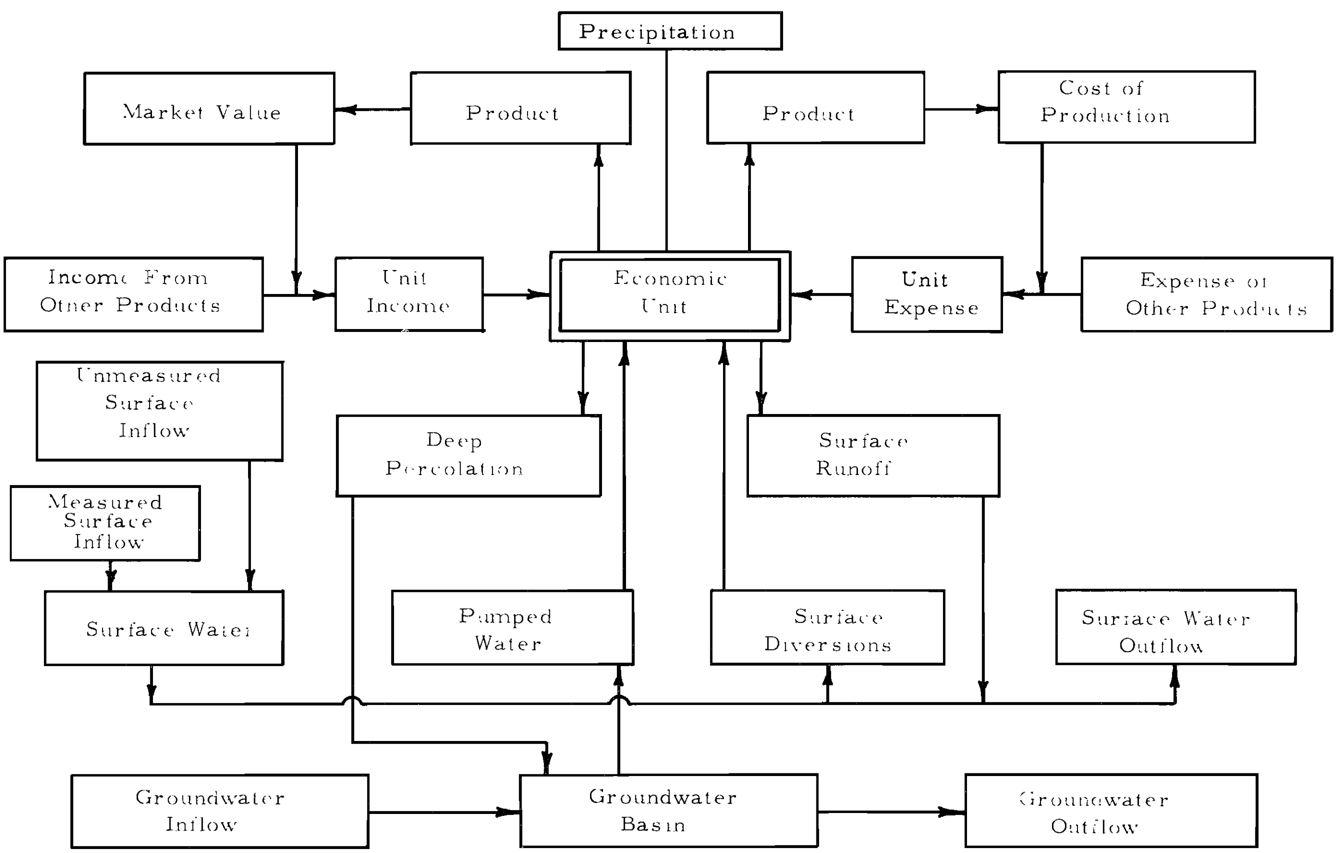

Figure 5.1. A general flow chart of a typical hydrologic-economic system.

occur from the soil alone. Thus, at the end of the growing period the seasonal or the accumulated evapotranspiration of each crop is computed and is introduced as the basic input to the economic model from the hydrologic system. Figure 5.2 shows the period for which evapotranspiration would be accumulated for corn.

Irrigation of the crops was based on a selected priority. If the water supply was insufficient to meet the crop demands and a crop did not receive water during an irrigation period, that crop was deleted from subsequent irrigation; because a water shortage at a critical growth level will stunt the crop and alter the production function. The assumption that a stunted crop has no yield is true for cash crops such as sugar beets and small truck crops but is less accurate for alfalfa and grains. The practice of excluding the crop from irrigation once it is shorted is quite realistic since irrigation supplies seldom recover sufficiently in the same year the shortage occurs.

Crop Production Functions

Productivity is one measure of the success of a farm operation. It may be defined in either physical or economic terms. With respect to agriculture, the physical productivity is the annual yield of crops grown on the farm. Economic productivity is the gross annual monetary return received from selling the crops produced.

A production function determines the relationship between the variation in yields of several crops resulting from a variable input of water, which is estimated in this study by assuming that all inputs required for crop growth, except water,

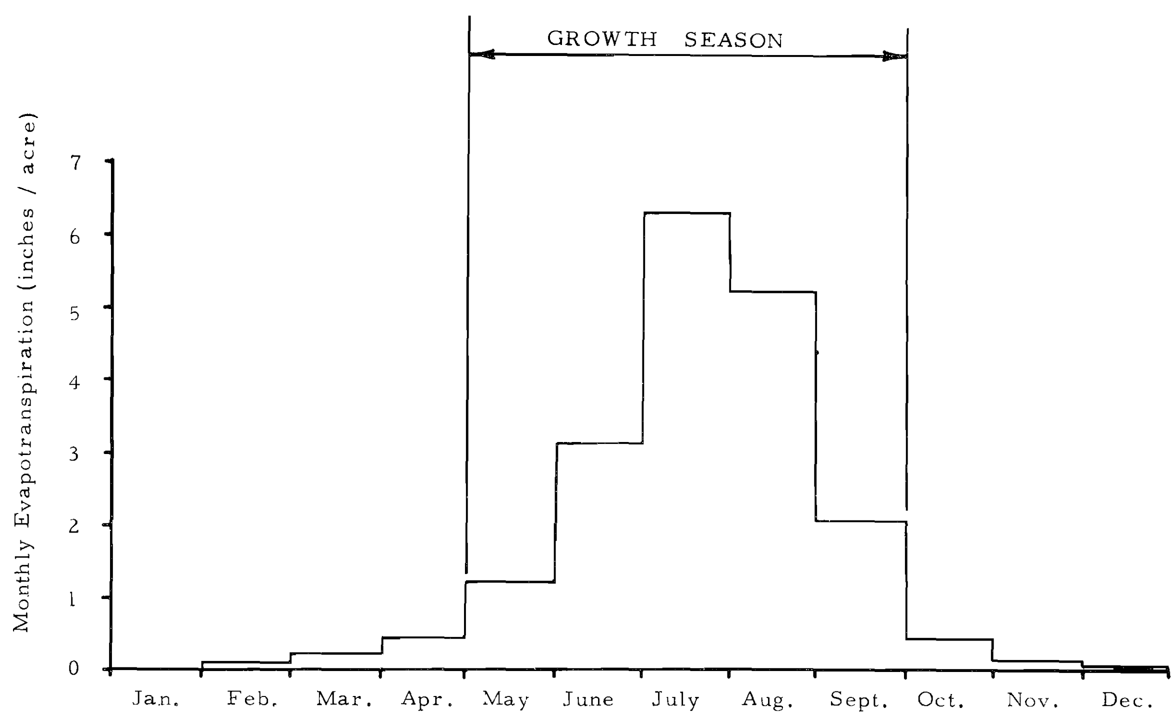

Figure 5.2. Period of seasonal evapotranspiration accumulation for growth season of corn.

have been held constant. The inputs such as fertility level, management, and machinery will remain almost constant from one year to the next because the study farm represents an aggregation of all farms within the area. These inputs may change gradually over several years, but water will fluctuate from one year to the next.

Figure 5.3 shows the theoretical short-run production function for an agricultural crop. The curve TPP shows the total physical productivity per acre for a crop resulting from various quantities of seasonal evapotranspiration. The marginal physical product (MPP) corresponding to any point on the total yield curve is given by the slope of the tangent to the curve at that point. The average physical product (APP) corresponding to any point on the total physical product curve is equal to the slope of a ray from the origin to the point in question. The average physical product attains its maximum value when this ray is tangent to the total product curve. The marginal physical product is equal to the average yield at the maximum average yield value.

The relationships among total, average, and marginal yields are used to define three stages of production, as illustrated in Figure 5.3. A rational producer would never produce in stage I because the fixed inputs are present in uneconomically large proportions to the variable inputs. To produce here would sacrifice a greater average product per unit

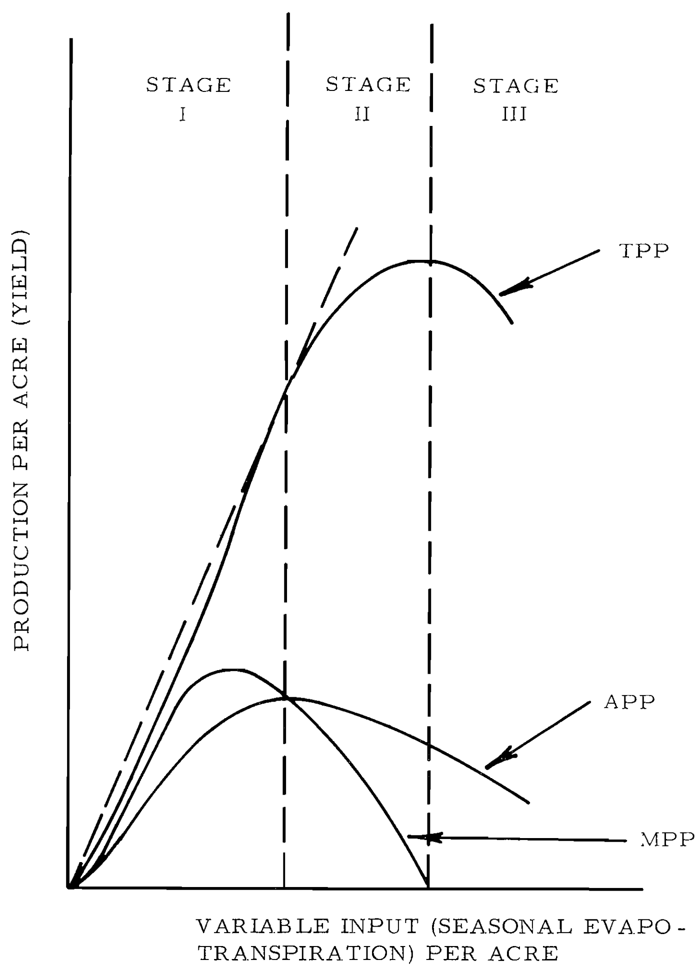

Figure 5.3. Typical short-run production function of an agricultural crop.

of input. Increasing average returns to the variable input are associated with negative marginal returns to the fixed input. For similar reasons rational production would not occur in stage III; additional units of inputs will decrease total yield.

The economical point of production will be determined by the prices and/or scarcity of inputs. In Cache Valley the variable factor for irrigation water is the supply rather than the price. If the water supply is insufficient to meet requirements of production in the rational range for a given farm, a portion of the acreage will be dry farmed or left idle so that the remaining acreage can receive adequate irrigation and produce in the rational range. If the supply exceeds the rational production requirement, the excess water is either sold or wasted; since the application of additional water will reduce rather than increase per acre yields.

The production functions used to represent the whole study area are intended to reflect averages for each crop for the entire area. Individual farms will produce higher or lower yields than those indicated by the production functions. In any case, there is a point of maximum yield for a farm and a set of conditions where additional water will not increase and may reduce yield. If yield is to be increased beyond this point, fixed factors, such as fertility, must be increased.

The quadratic curves that are assumed to define the production functions are shown in Figure 5.4 and Appendix C. Using these curves, it is possible to find the estimated yield from a particular crop once the seasonal evapotranspiration is known, assuming that the production functions have been established correctly for the existing conditions. The importance of the crop production function in linking hydrologic to economic systems is illustrated in Figure 5.5.

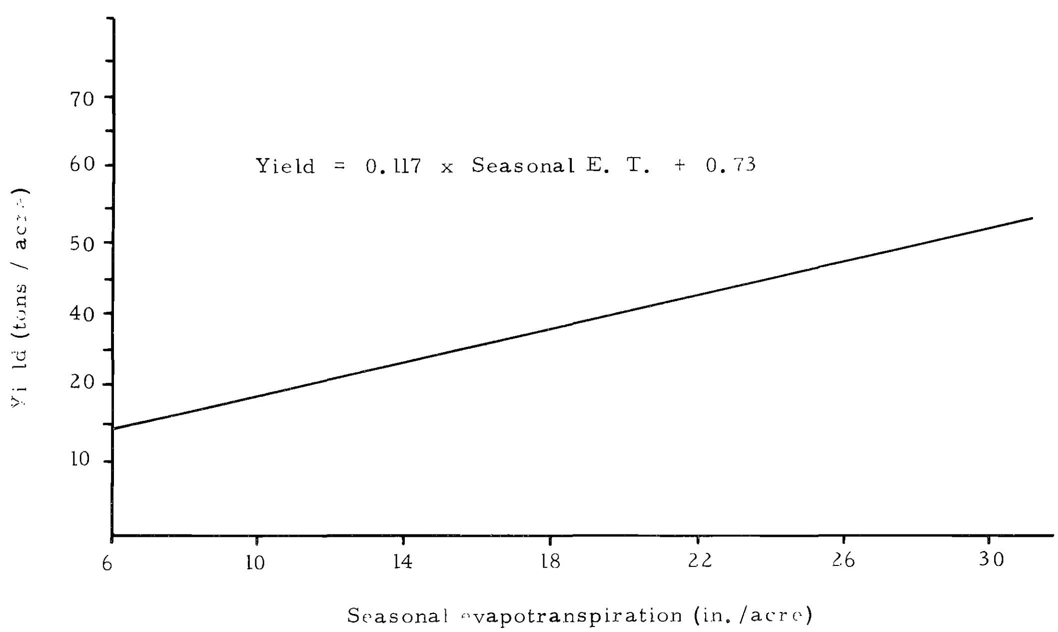

Figure 5.4. Seasonal evapotranspiration-yield relationship for alfalfa.

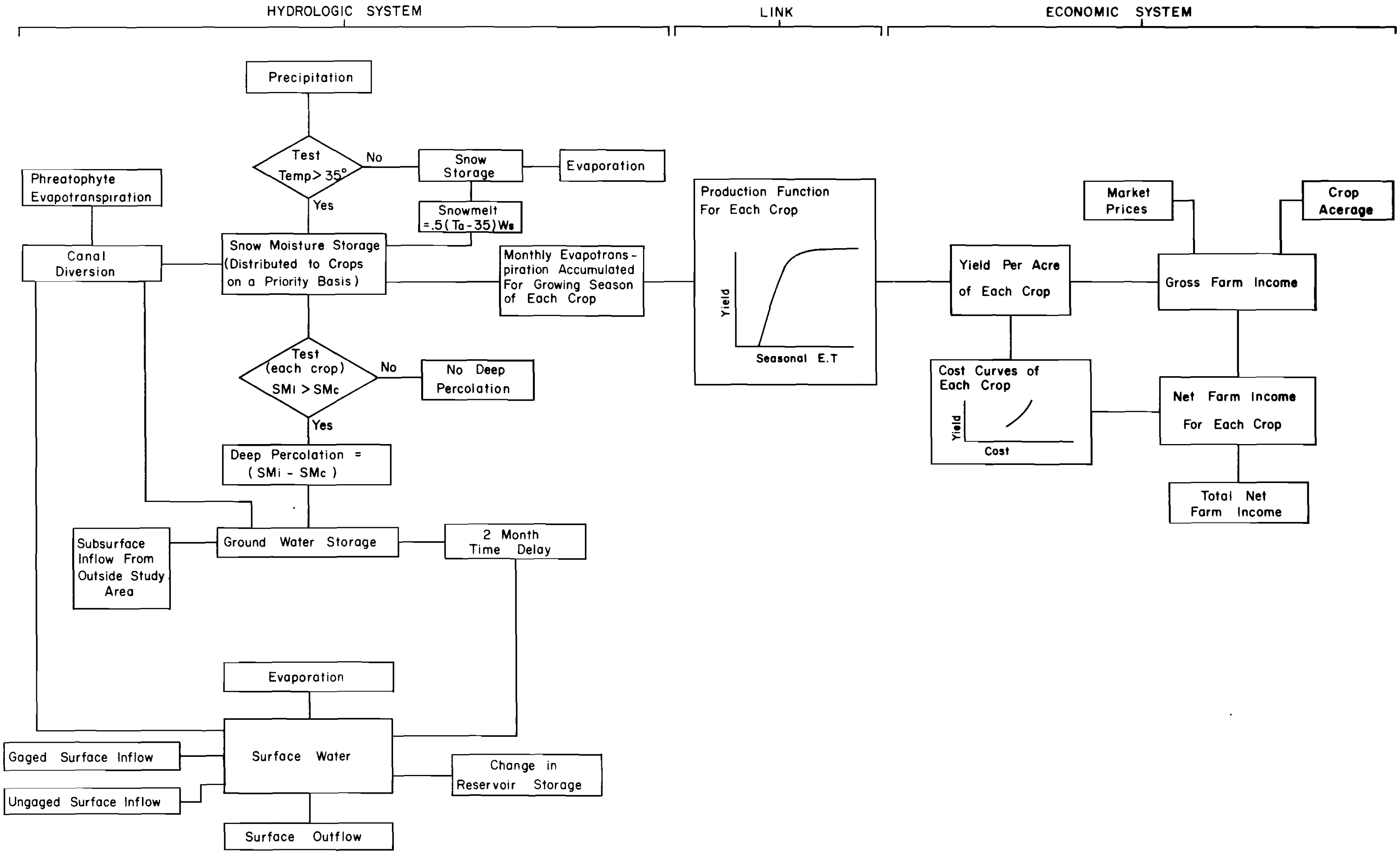

Figure 5.5. The production function as the link between the hydrologic and economic models.

CHAPTER VI
COMPUTER PROGRAMMING

The mathematical model of the hydrologic system was programmed on the analog computer for testing and verification. By analog computer verification, the model or basin parameters which establish the uniqueness of the model are determined. In this phase of establishing model uniqueness, the analog computer has an advantage in the fact that the model builder gains a keen insight into the physical system processes and an understanding of system responses to induced changes.

The hydrologic system model, rendered unique by the analog computer verification, was then programmed in Fortran IV language for digital computer computations. The economic model was originally programmed in Fortran IV. Additional analysis consisted of testing and verifying the total hydrologic-economic model. The various assumptions made at different stages of computer programming are discussed in this chapter.

Analog Computer Program

The first step in developing the analog computer program of the hydrologic system is to express the various hydrologic processes by a set of algebraic or differential equations.

Time is the independent variable in analog computer programs. All dependent variables must, therefore, be functions of time, and their derivatives will be with respect to time. Programming of the physical problem makes use of this characteristic time dependent behavior of the analog variable. Physical variables are represented with suitable scales in terms of the dependent analog variable, voltage, and the independent analog variable time. The various phases of the hydrologic system are interrelated by the concept of continuity of mass.

Scaling

Programming an analog computer requires the scaling of time and magnitude in order to operate within the capabilities of the computer. Scaling of time corresponds to scaling the independent variable. Scaling of magnitude corresponds to scaling the dependent variable of the problem (voltage) which is related to the various hydrologic values such as precipitation and surface inflow.

Time scaling. Selection of a suitable time scale for the analog computer program depends upon the nature of the mathematical expressions, the input data, and the nature of the problem objectives. In the present model, the mathematical expressions do not involve any periodic functions and so the limitations imposed by the frequency responses need not be considered in selecting a time scale. The problem nature and its objectives are concerned with monthly or sometimes even yearly changes in the phenomena such as annual evapotranspiration and economic returns. The input data such as precipitation and temperature are available in average monthly values. For these reasons, a time scale of one month of real time equal to one second of the computer time is adopted.

The inputs of the model are step functions where each step or value corresponds to the variable occurring in any time increment, Δt, of one month in real time or one second of computer time.

For studies requiring more accuracy, smaller values of Δt are desirable. The value of Δt should be as small as possible within the reasonable limitations of related data, time, and expenses involved.

Amplitude scaling. The choice of a proper amplitude scale factor is important to the accuracy of the analog computer program. Amplitude scaling is done with the following considerations.

1. Voltage levels throughout the computer model are maintained within an optimum range. The normal operating range of the computer is ± 100 volts; therefore, an attempt is made to keep all peak voltages close to ± 100 volts.
2. The relationship between the physical and analog systems are preserved to ensure correct conversion of the analog voltages to physical units.

The amplitude scale factors adopted in this study are:

1. Precipitation and other forms of water such as soil moisture, evapotranspiration, stream flow, etc., are actually measured in inches. The scale factor for converting them to the computer variables is one inch equals 10 volts.
2. In the computation of evapotranspiration and snowmelt, the average monthly temperature is an important input. The physical units of average monthly temperature in ^{o}F are converted to the computer values by the scale of 1.0^{o}F equal to 1.0 volt.

These amplitude scale factors are found to be appropriate for the study because all hydrologic measurements are in inches and the computer output is in voltage which is converted to inches or acre-feet as desired. Further, these scales ensure that there is no overloading of any of the analog computer components.

After the system of equations has been formulated, time scaled, and amplitude scaled, the model can be programmed on the analog computer. Programming of an analog computer is accomplished by interconnecting the computer components in such a manner that the mathematical operations called for in the equations are performed by the computer. The analog program is normally recorded in the form of a flow chart.

The analog model corresponding to the hydrologic system under investigation (Figure 3.1) is shown in Figure 6.1.

Digital Computer Program

This phase of the study involved: (a) Transferring the analog computer model of the hydrologic system to a digital program, (b) forming the economic model, and (c) linking the two models together by applying the associated crop production functions.

Hydrologic model

The conversion of the analog hydrologic model to a digital program is a relatively straight-forward procedure. The hydrologic parameters and mathematical relationships already developed are utilized in the digital program. However, a few basic changes are needed for such a conversion because the analog computer deals with continuous forms of the parameters while the digital program operates with discrete forms of data.

Precipitation. A continuous precipitation input condition was approached on the digital model by considering precipitation to enter the soil moisture storage on a daily basis rather than on a monthly basis. Each day, one-thirtieth of the monthly precipitation is added to the soil moisture storage of the land upon which it fell. This is necessary because of the relationship of soil moisture to evapotranspiration.

Snowmelt and snow storage. The relationship between snowmelt and snow storage also requires continuous computations. In the digital computer program, these values are calculated daily rather than monthly. The amount of snowmelt computed for each day is subtracted from storage, and the soil moisture is increased correspondingly.

Evapotranspiration. Since the evapotranspiration rate and the soil moisture storage are

Table 7. 1. Values of analog program parameter for Cache Valley hydrologic model.

Pot. No.*	Analog Program Parameters	Potentiometer Value 1944	1945
2	Gain factor	0. 100	0. 100
3	Unmeasured G. W. inflow/measured surface inflow	0. 200	0. 200
6	Lower limit of potential evapotranspiration	0. 200	0. 200
8	Lower limit of potential evapotranspiration	0. 200	0. 200
9	Bias for comparator	0. 005	0. 005
13	Ten times previous year precipitation (Nov. and Dec.)	0. 210	0. 210
14	Constant for groundwater feedback circuit	0. 920	0. 920
15	Snowmelt correlation	0. 430	0. 430
17	Scale factor for soil moisture input to evapotranspiration equation	0. 800	0. 800
18	Available soil moisture capacity (ten times)	0. 560	0. 450
20	Water surface evaporation	0. 045	0. 045
23	Unmeasured surface inflow correlation	0. 230	0. 230
24	Ten times soil moisture	0. 110	0. 300
25	Initial condition for groundwater inflow	0. 150	0. 000
26	Precentage of phreatophyte evapotranspiration from reservoir	0. 650	0. 650
27	Percentage of phreatophyte evapotranspiration from soil moisture	0. 350	0. 350
30	Value of k from infiltration equation	0. 500	0. 500
33	Evapotranspiration equation coefficient	0. 325	0. 325
34	50 times evapotranspiration equation coefficient	0. 880	0. 880
37	Canal efficiency	0. 650	0. 650
38	Freezing temperature	0. 315	0. 315
39	Scale factor for precipitation	0. 050	0. 050
40	Water surface area/total area	0. 240	0. 240

*Potentiometer numbers are taken from Figure 6. 1.

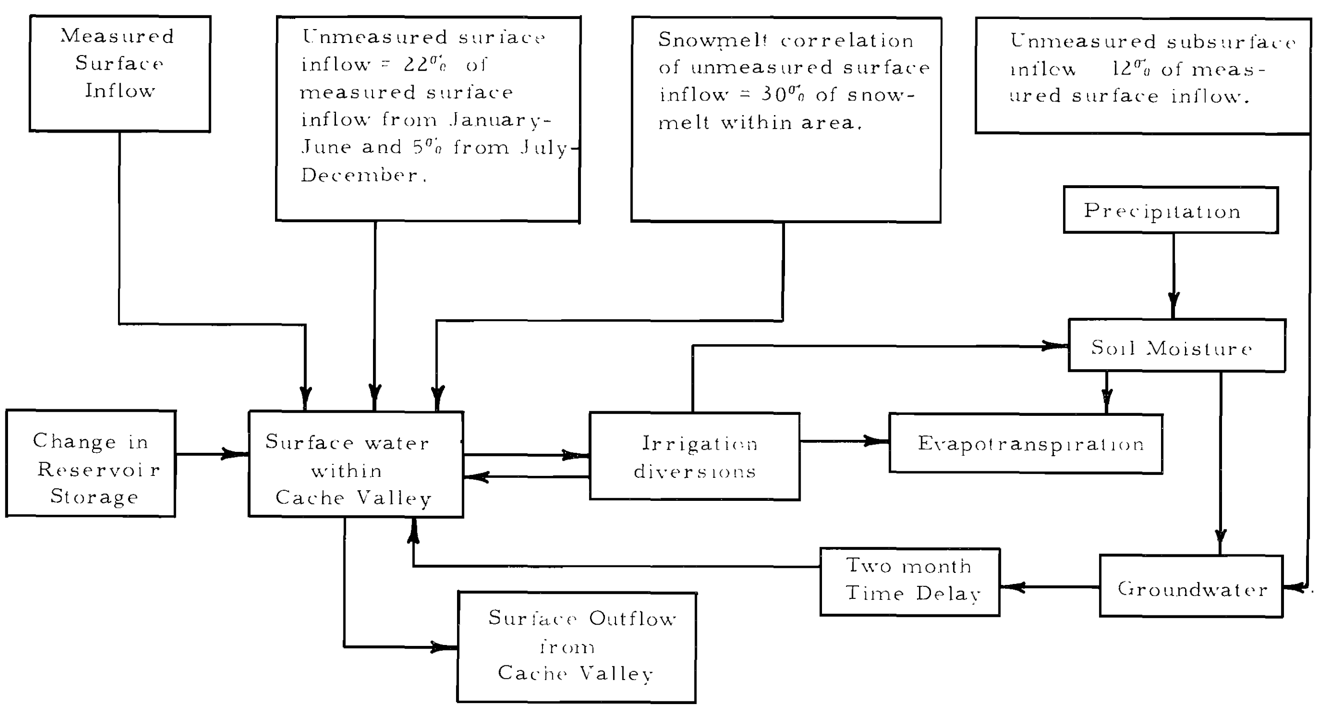

Figure 7.2. Summary of basic hydrologic parameters used for hydrologic-economic model.

Verifying the Hydrologic-Economic Model

The basin parameters determined from verification of the digital hydrologic model are slightly different than the parameters obtained from the analog study. This slight difference results from adjustments made in the basic model. These changes included: (a) separate soil moisture storage for each crop, (b) an approximation to the method of continuous computations by the analog computer, and (c) two applications of irrigation water every month insteady of continuous applications. The combination of hydrologic basin parameters used in the final hydrologic-economic model is summarized in Figure 7.3.

The computer program is written in such a way that any number of years can be continuously simulated. The hydrologic conditions existing at the end of one year are used as initial conditions for the following year. Figure 7.4 compares the analog, digital, and measured outflow from Cache Valley for 1944 and 1945. The computer output for the year 1944 is shown by Tables 7.2 and 7.3. Similar output for the following year is included in Appendix C.

The water use-crop yield relationship (production function) is used to link the hydrologic and economic models. This integrated model is used as a tool in establishing a reliable guide to the yield expectations for various crops associated with seasonal levels of water use.

Verification of the hydrologic-economic model consisted of testing the computer program under various hydrologic and economic conditions which ensured that the model gave consistent reasonable results for the given conditions. The agricultural economic information included production functions, market prices, and production costs of the present period.

The net farm return values predicted through the present economic conditions and normal hydrologic conditions are within the range that is expected; however, it is not possible to verify individual output data in view of the inadequacy of the economic data available. The model is considered to be verified if the predicted values of economic outputs are within the proper range for the given changes in the hydrologic model. Since the economic model outputs seemed reasonable, the model was regarded as verified.

Table 7.2. Digital computer model output of hydrologic values, 1944.

HYDROLOGIC SIMULATION OUTPUT FOR THE YEAR 1944

	JAN	FEB	MAR	APR	MAY	JUN	JLY	AUG	SEP	OCT	NOV	DEC	ANNUAL
PRECIPITATION(IN)	1.05	.83	1.51	3.07	.97	3.13	.29	.79	.35	.32	2.02	1.10	15.43
AVERAGE TEMPERATURE	14.70	25.30	31.30	42.60	53.70	59.00	67.10	55.20	57.20	50.80	30.90	23.60	
PERCENT DAYLIGHT HOURS	6.60	6.66	8.28	9.97	10.10	10.21	10.37	9.64	8.42	7.73	6.63	6.39	
1 BEETS KC COEF	.25	.25	.25	.25	.35	.66	1.10	1.25	1.14	.25	.25	.25	
2 CORN KC COEF	.25	.25	.25	.25	.37	.75	1.08	1.03	.65	.25	.25	.25	
3 GRAIN KC COEF	.25	.25	.25	.26	.50	1.54	1.12	.25	.25	.25	.25	.25	
4 ALFALFA KC COEF	.63	.73	.86	.98	1.08	1.13	1.11	1.05	.98	.90	.78	.64	
5 PASTURE KC COEF	.48	.58	.74	.86	.90	.93	.91	.91	.86	.79	.64	.52	
6 LAND PHRYTS KC COEF	.70	.70	.75	.81	.89	1.02	1.18	1.28	1.29	1.19	1.04	.86	
7 WATER PHRYTS KC COEF	.70	.70	.75	.81	.89	1.02	1.18	1.28	1.29	1.19	1.04	.86	
ACCUM SNOW STORAGE	1.65	2.48	1.75	.05	.00	.00	.00	.00	.00	.00	1.26	2.36	
SNOW MELT	.00	.00	2.24	1.70	.05	.00	.00	.00	.00	.00	.76	.00	4.75
E. T. OF BEETS	.00	.05	.15	.40	1.17	2.81	6.48	6.39	3.71	.55	.11	.04	21.87
E. T. OF CORN	.00	.05	.15	.40	1.23	3.19	6.36	5.27	2.11	.55	.11	.04	19.48
E. T. OF GRAIN	.00	.05	.15	.42	1.67	6.56	6.60	1.28	.81	.55	.11	.04	18.24
E. T. OF ALFALFA	.00	.15	.51	1.58	3.60	4.81	6.54	5.42	3.19	2.00	.35	.09	28.25
E. T. OF PASTURE	.00	.12	.44	1.39	3.00	3.56	5.36	2.93	1.54	1.10	.16	.05	20.06
E. T. OF LAND PHYTS	.00	.15	.44	1.31	2.97	4.34	6.95	5.74	2.00	.85	.15	.06	24.96
E. T. OF WATER PHYTS	.00	.15	.44	1.31	2.97	4.34	6.95	6.55	4.20	2.54	.47	.12	30.14
E. T. OF WATER SURFACE	.00	.21	.59	1.62	3.34	4.26	5.89	5.12	3.25	2.22	.45	.14	27.08
SOIL MOIST BEETS (IN)	6.00	5.95	8.04	9.00	8.97	9.00	7.97	8.07	8.44	8.21	8.85	8.82	
SOIL MOIST CORN (IN)	6.00	5.95	8.04	9.00	8.96	8.99	7.99	8.25	8.71	8.47	9.00	8.96	
SOIL MOIST GRAIN (IN)	3.00	2.95	5.04	6.00	5.88	5.43	4.95	4.46	4.00	3.76	4.41	4.38	
SOIL MOIST ALFLFA (IN)	6.00	5.85	7.58	9.00	8.56	8.72	6.64	8.23	8.53	6.85	7.26	7.17	
SOIL MOIST PASTRE (IN)	3.00	2.88	4.68	7.50	7.05	7.36	2.56	.81	1.69	.91	1.51	1.46	
SOIL MOIST LD PHT (IN)	3.00	2.85	4.65	8.11	7.34	8.13	4.16	1.15	.95	.43	1.04	.98	
MEASURED INFLOW	41967.	40579.	48754.	80670.	133299.	118615.	99718.	85859.	60111.	34962.	39944.	41350.	825828.
UNMEAS SUP INFLOW(AF)	9233.	8927.	10726.	17747.	29326.	26095.	4986.	9293.	3006.	1743.	1997.	2067.	120152.
CHANGE IN RES STORAGE	-5900.	2980.	-2730.	7700.	0.	9630.	-14860.	580.	1870.	-2130.	-2350.	3660.	-1530.
CALCULATED RES OUTFLOW	57762.	58667.	82047.	104792.	130667.	94787.	54310.	48997.	41854.	59891.	70703.	53388.	857864.
CANAL DIVERSIONS	0.	0.	0.	0.	86196.	146691.	197682.	142806.	106311.	0.	0.	0.	679686.
DEEP PERCOL TO G W(AF)	0.	0.	0.	28384.	8620.	14905.	19768.	14281.	10631.	0.	90.	0.	96678.
GROUNDWATER INFLOW(AF)	5036.	4869.	5850.	9680.	15996.	14234.	11966.	10303.	7213.	4195.	4793.	4962.	99099.
DEEP PERCL+GW INFL(AF)	5036.	4869.	5850.	38064.	24615.	29138.	31734.	24584.	17844.	4195.	4883.	4962.	195777.
DELAY LEVEL 2 (AF)	24000.	5036.	4869.	5850.	38064.	24615.	29138.	31734.	24584.	17844.	4195.	4883.	
LEVEL 1 BEFOR OTFL(AF)	0.	24000.	17036.	13387.	12544.	44335.	46784.	52530.	57999.	53583.	44636.	26514.	
LEVEL 1 AFTER OTFL(AF)	0.	12000.	8518.	6694.	6272.	22168.	23392.	26265.	29000.	26792.	22318.	13257.	
GW TO SUR FM LEV 1(AF)	0.	12000.	8518.	6694.	6272.	22168.	23392.	26265.	29000.	26792.	22318.	13257.	196675.
1 BEETS IRRIG(IN/AC)	.00	.00	.00	.00	.45	.00	20.64	22.81	14.93	.00	.00	.00	
2 CORN IRRIG(IN/AC)	.00	.00	.00	.00	.67	.38	20.29	18.98	6.97	.00	.00	.00	
3 GRAIN IRRIG(IN/AC)	.00	.00	.00	.00	2.12	11.88	23.32	.00	.00	.00	.00	.00	
4 ALFALFA IRRIG(IN/AC)	.00	.00	.00	.00	8.57	7.36	16.68	24.89	12.55	.00	.00	.00	
5 PASTURE IRRIG(IN/AC)	.00	.00	.00	.00	6.11	4.58	1.10	1.56	8.27	.00	.00	.00	
6 LD PHYT IRRIG(IN/AC)	.00	.00	.00	.00	4.70	8.00	10.78	7.78	5.80	.00	.00	.00	

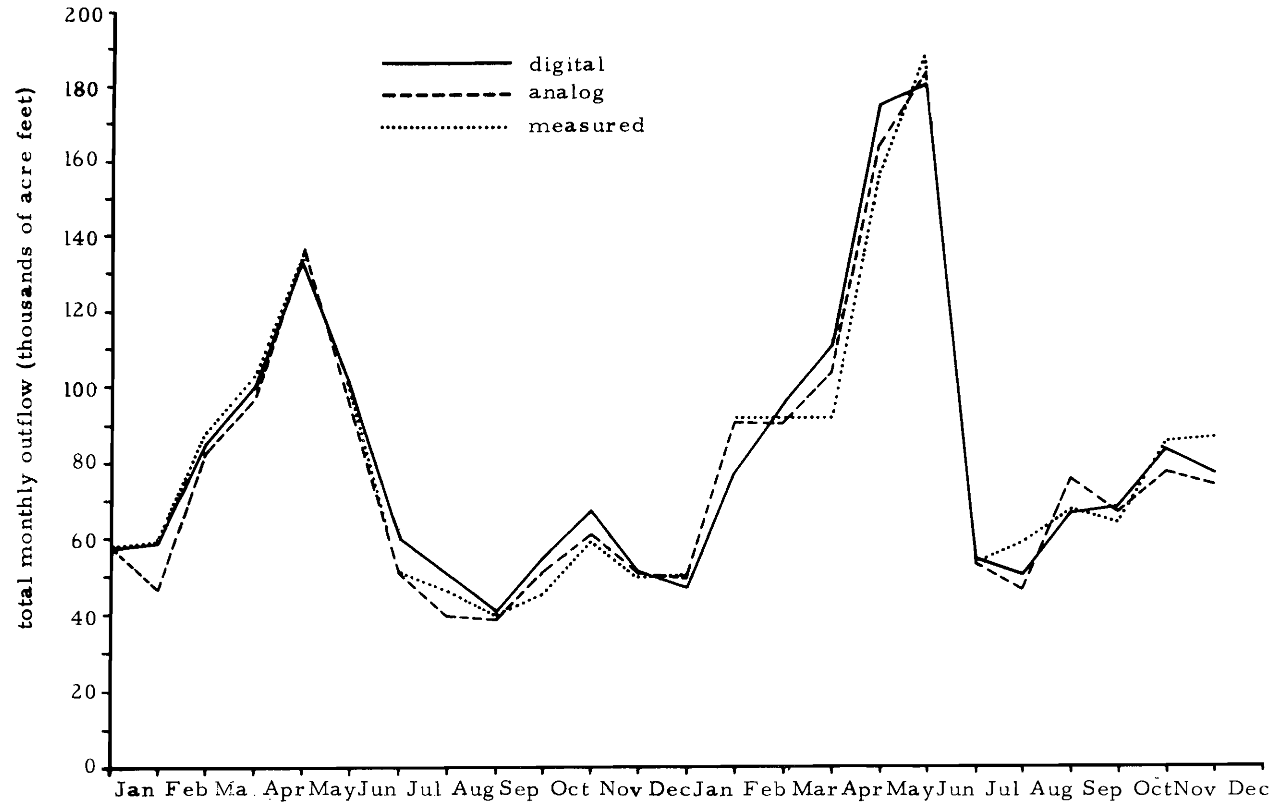

Figure 7.3. Predicted digital and analog outflows from Cache Valley compared to the measured outflow for 1944 and 1945.

Table 7.3. Digital computer model output of economic values, 1944.

ECONOMIC SIMULATION OUTPUT FOR THE YEAR 1944

	BEETS	CORN	GRAIN	ALFALFA	PASTURE	LND PHYTS	WTR PHYTS	WATER
CROP AREA(AC)	9824.	8967.	47208.	49799.	51300.	17611.	20660.	7567.
ROOT DEPTH (FT)	6.00	6.00	4.00	6.00	3.00	6.00		
AVA WTR HOLD CAP(IN/FT)	1.50	1.50	1.50	1.50	2.50	1.50		
AVA WTR CAP (IN)	9.00	9.00	6.00	9.00	7.50	9.00		
SEASONAL E T(IN/AC)	20.56	18.18	14.82	28.25	20.06	24.96	30.14	27.08
SEASON IRR DIV (IN/AC)	58.84	49.20	37.32	70.04	21.61	9.26		
CROP PRICE($/UNIT)	16.60	7.00	1.05	21.00	5.50			
CROP YIELD(UNIT/AC)	17.20	18.19	59.99	4.04	5.36			
GROSS RETURN($/AC)	293.53	127.31	66.90	89.24	29.50			
COST PER ACRE($/AC)	170.02	102.93	69.34	65.08	28.55			
NET RETURN($/AC)	123.51	24.37	-2.44	24.16	.95			
TOTAL NET RETURN FROM THE ENTIRE AREA=		2568507.						

CHAPTER VIII
RESULTS AND DISCUSSION

The mathematical relationships of the model are general in nature and, by appropriate verification procedures, can be applied to any geographic area.

The success of a verification procedure depends upon sufficient and accurate data. For example, the hydro-economic model would demand more confidence if the production function curves had been defined more precisely. However, isolation of one factor, such as water, as a measurement of production in the complex process of crop growth and yield is very difficult and has not yet been accomplished. Precise data concerning seasonal evapotranspiration of a crop and the resulting yield should be gathered. The model would be easier to apply to other basins if a method of transposing production functions to other areas were devised. This technique could be a non-dimensional procedure similar to the unit graph approach of estimating a runoff hydrograph. The level of the production functions and the shapes of the functions should take into account all the factors affecting crop yield which, in this study, were assumed to be constant.

Typical output and applications of the hydrologic-economic model developed in this study are presented in this chapter.

Analog Hydrologic Model

Soil moisture storage

The computed values of available soil moisture content of the irrigated crop land are shown in Figure 8.1 and Appendix B. The flat portion of the soil moisture curve at 5.60 inches results from the assumption that the maximum soil moisture storage capacity equals 5.60 inches.

Evapotranspiration

The monthly evapotranspiration from phreatophytes is shown in Figure 8.2. Phreatophytes were considered in two groups based on whether they were growing on land within the area or growing in water within the area.

The monthly evapotranspiration from agricultural crops is lumped together in the analog model. This does not affect the verification of the model but makes it more difficult to study the evapotranspiration from one particular crop. Evapotranspiration was separated according to each crop in the final model. The combined monthly crop evapotranspiration is shown in Figure 8.3.

Groundwater

The groundwater system consists of underground inflow to the valley from the surrounding mountains and deep percolation from the root zone. The water entering the groundwater system is delayed two months before it enters the surface water system in the valley. The analog calculation of delayed groundwater entering the surface water is shown in Figure 8.4 and Appendix B.

Snow storage

Computed values of snow storage equivalent for the area are shown in Figure 8.5 and Appendix B. The snow storage at the end of 1944 was used as initial conditions of snow storage for 1945. Snowmelt occurring in the spring months from the winter snow accumulation is shown in Figure 8.6. The analog computer calculates the snowmelt continuously during the month. Snowmelt is dependent upon snow storage and mean monthly surface air temperature. The decrease in snow storage, as the snow melts, accounts for the decreasing rate of snowmelt during

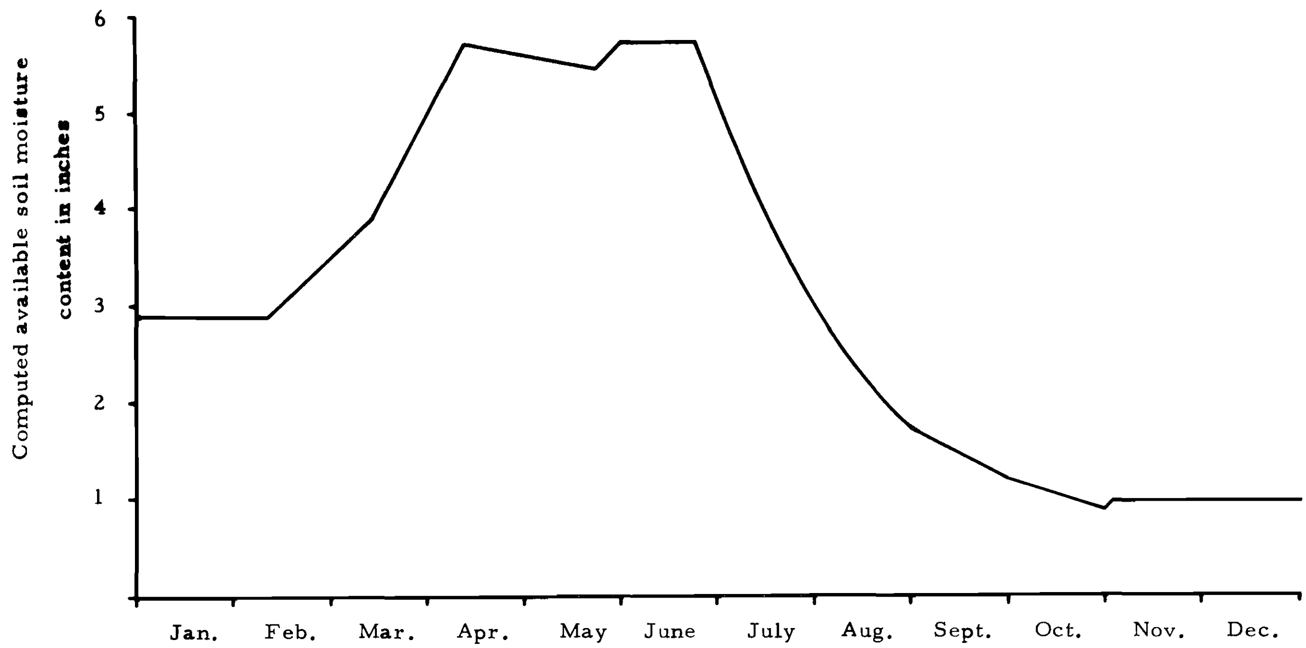

Figure 8. 1. Computed available soil moisture content in inches, 1944.

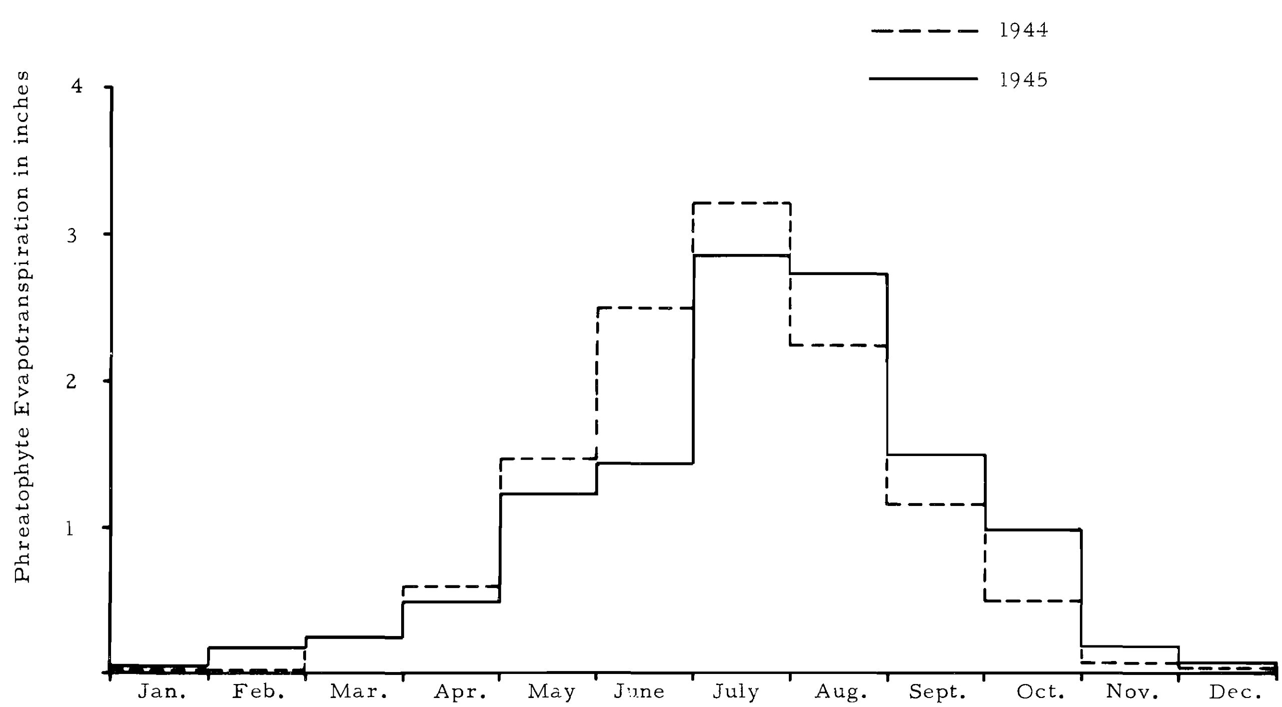

Figure 8. 2. Phreatophyte evapotranspiration in inches.

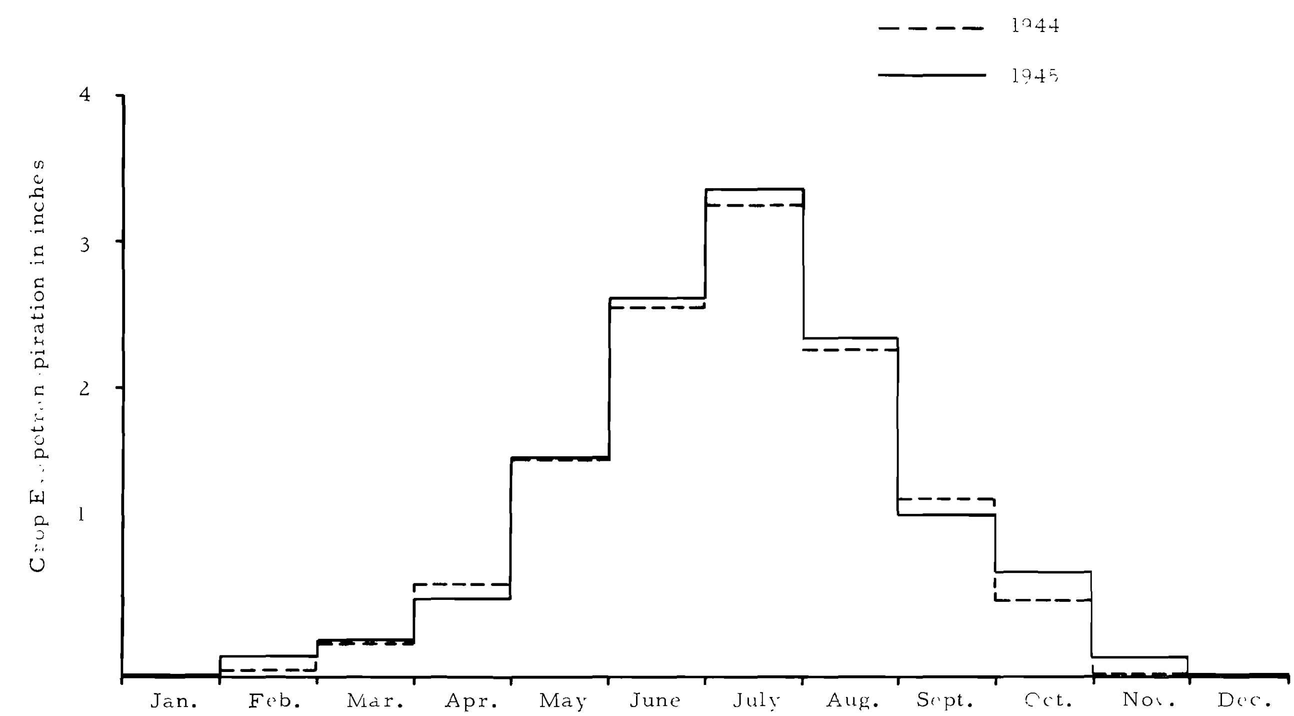

Figure 8.3. Crop evapotranspiration (in inches over the entire area).

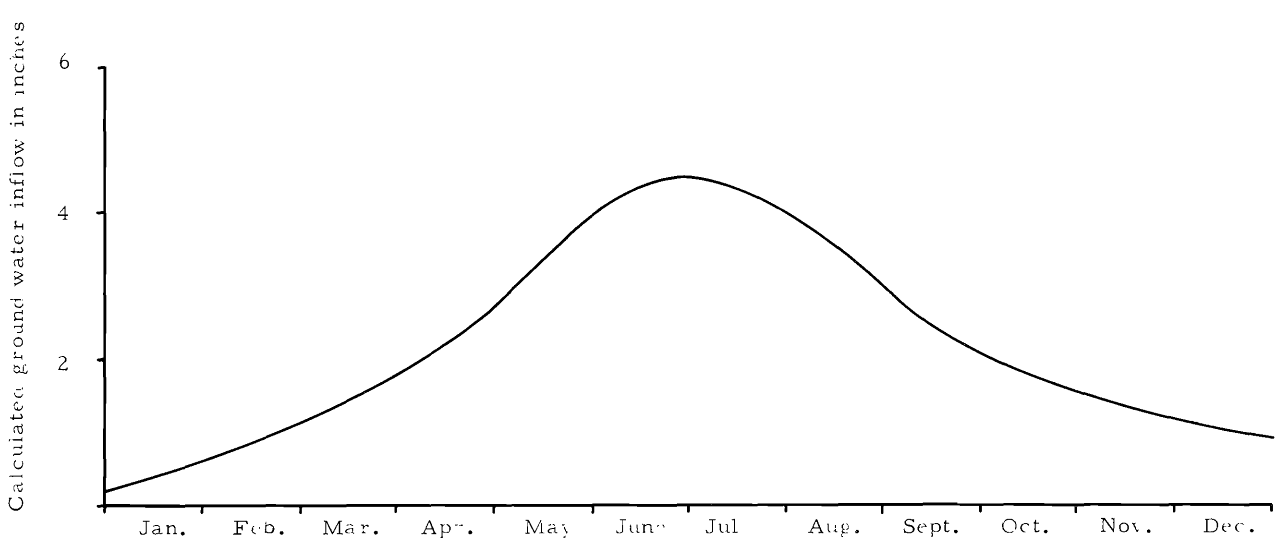

Figure 8.4. Analog calculated groundwater inflow (in inches over the entire area), 1944.

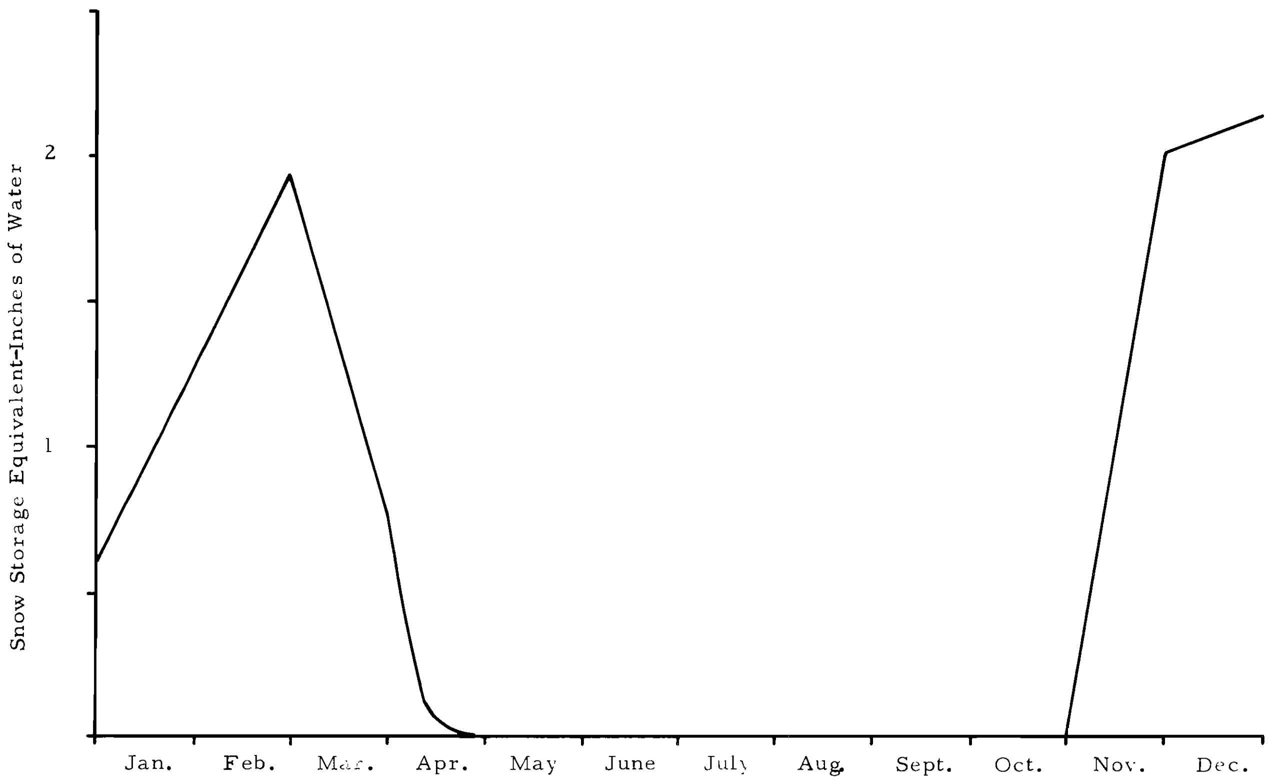

Figure 8. 5. Analog computed snow storage equivalent (in inches over the entire area), 1944.

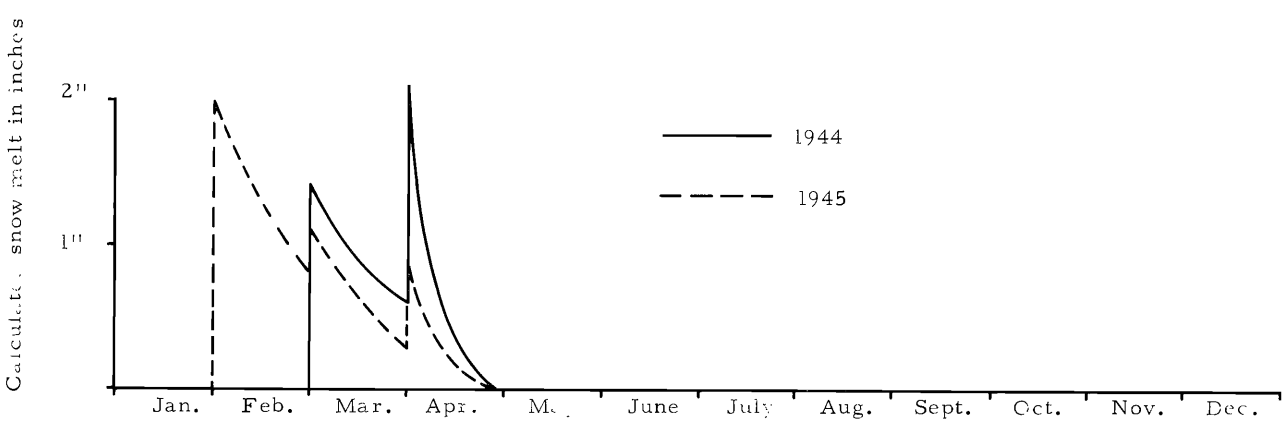

Figure 8. 6. Analog calculated snowmelt in inches for Cache Valley.

a particular month. At the beginning of the next month it is associated with a different mean monthly temperature. This explains the sudden change in level of melting at the beginning of each month. The snow storage and melt usually approach zero by the end of April.

As snowmelt occurred within Cache Valley, water was assumed to go directly into soil moisture with no associated runoff because of the relatively flat nature of the area.

The snowmelt equation constant, k_s, of Equation 3.2 was found to be 0.2. The relatively high value was attributed to the fact that the snowpack was relatively shallow for the area modeled, compared to a mountain watershed.

Digital Hydrologic-Economic Model

The values of water with reference to each of the various competing uses has received considerable attention in the past, especially with respect to agricultural irrigation water. The actual value of a unit of water determines the maximum amount a farm manager can pay for an additional unit of water or for improving the efficiency of an existing system. The following sections discuss the results of this study with respect to determining the value of agricultural water.

The marginal values of Figure 8.7 are derived by observing the change in net farm income associated with a small change in water supply. A change in water supply can be effected by reducing or increasing the quantity of canal diversions while other input values are unchanged. The variation in net return will, then, be the result of changes in canal diversions. These values provide an estimate of the marginal return to farm labor at various water levels. As canal diversions become smaller, the marginal return generally becomes greater. These values are shown in Figure 8.7 for several cropping patterns. The cropping patterns used in this study are identified in Table 8.1.

The marginal value curves of Figure 8.7 illustrate where the water is going with respect to the crops produced. Each point represents the value of one acre foot of water applied at a given level of water supply. The curves indicate the marginal value of water at various levels of water supply for a particular cropping pattern.

The curves illustrated in Figure 8.7 represent four cropping patterns related mainly to changes in the relative size of cash crops. The marginal values of all cropping patterns drop to zero near 3.0 acre feet per acre, then rise and fall to zero again. The marginal value goes to zero at the intermediate value because additional units of water fill the soil moisture storage of alfalfa but do not contribute to evapotranspiration or yield. However, due to the priority schedule of water delivery, as more water is added, the soil moisture reservoir of alfalfa becomes full, and additional water can be turned to pasture. Thus, the marginal value curves rise again and fall to zero as the pasture areas receive sufficient water to satisfy potential evapotranspiration. The same phenomena of marginal values going to zero would occur for each crop, however, it would occur at lower marginal values of water due to the smaller acreages associated with crops of higher priorities. If control of soil moisture could be maintained, increased returns could be achieved during years of water shortage by applying water to crops only in amounts which would prevent water shortage to the plants. Soil saturation is generally associated with irrigation and involves a certain amount of dead storage. The marginal value curves of Figure 8.7 drop to zero at points where additional increments of water go into dead storage. This dead storage is available to the agricultural crop if temperatures higher than normal or a shortage of water late in the season require the crops to use it. A farm manager will try to fill some dead storage, especially for cash crops, because of future uncertainties. The cost of this water could be thought of as an insurance cost against water storage.

Table 8.1. Various cropping patterns used in this study.

Cropping Pattern Number	Crop	Sugar Beets	Corn	Grain	Alfalfa	Pasture
1*		9,824	8,967	47,208	49,799	51,300
2		19,824	8,967	37,208	49,799	51,300
3		0	8,967	47,208	59,623	51,300
4		0	0	57,031	58,765	51,300

* Actual mapped cropping pattern (Haws 1969a) with miscellaneous cash crops included as sugar beets.

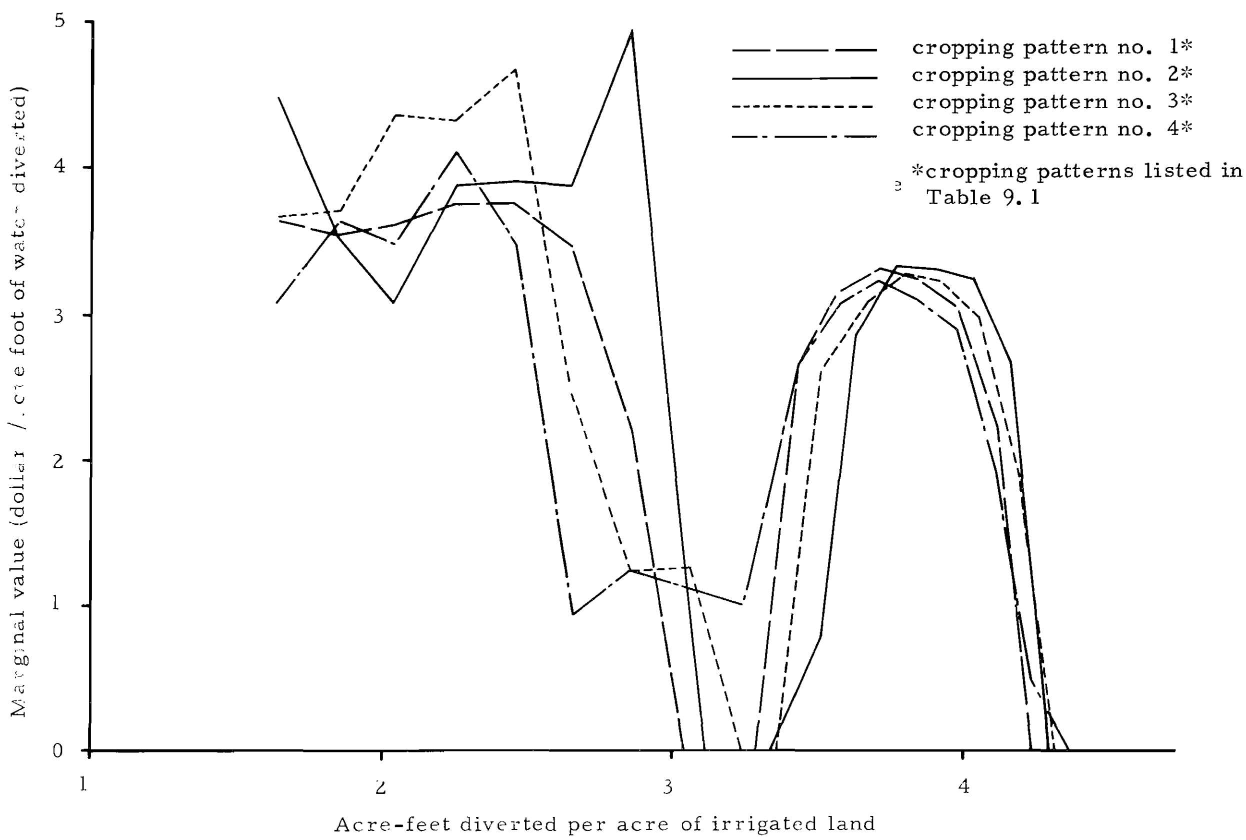

Figure 8.7. Marginal value of net return to farm management related to the amount of irrigation water diverted.

Marginal values of water can also be estimated by attributing a reasonable cost to farm labor rather than water. The net residual return would then be the return due to water. The availability of water with respect to time is a very important factor in determining its value to a particular farm. Water is much more valuable at critical periods than it is during spring runoff.

Agriculture is the greatest consumptive user of water in Cache Valley and in most of the western states. If the present allocation of water to agriculture is to be maintained in competition with other water uses, it is necessary to use the water efficiently and with a competitive marginal value compared to the marginal value of the alternative uses.

In order to achieve a high efficiency in the use of irrigation water, it is necessary to know the relationship between crop yield and water consumption. Without this information it is impossible for farmers to decide how much water to apply or the price they can afford to pay for an additional unit of water, either from an outside source or by improving the efficiency of their system. In order to compare the values of water for various alternative uses it is necessary to evaluate the marginal value of water for each use.

Total values of net farm income

The hydrologic-economic model predicts the value of net farm income per acre. By considering the number of acres associated with each crop, the total net return of the agricultural unit (in this case Cache Valley) is determined for a particular year.

By changing only the level of canal diversions for a typical year, the model was operated repeatedly to obtain a series of total net return values. The results of this analysis are shown graphically in Figure 8.8 for several cropping patterns. This graph will be valuable in actual planning or management because it gives an indication of the overall effect of different water supplies for agricultural irrigation.

The total net return to farm management is closely related to the average monthly temperatures. Higher temperatures result in more evapotranspiration and more plant growth. To indicate the overall effect that a change in average temperature could have on net income, a typical year was simulated repeatedly with the same conditions except for small changes in the average temperatures. The total net return was then observed as a function of the change in temperature from this typical year. The results are shown in Figure 8.9.

Typical management applications of the model

The purpose of this study is to apply the simulation technique to both the hydrologic and agricultural economic systems for the purpose of evolving better management practices of the available water resource. The interrelationships between the hydrologic and economic systems, the effects of alternative water resource policies and designs, and variations in agricultural crop production are examined in this study. A few possible applications of this model are suggested in the following sections.

Evaluation of various cropping patterns. The combination of cropping patterns and the allocation of area for each crop are an important step in farm management. Many alternative cropping patterns can be investigated by this method. The internal effects of both the hydrologic and the economic systems can then be examined. The net return to the farm associated with each pattern may be obtained.

The best cropping pattern will depend upon such things as soil and climate conditions, predicted level of water supply for the season, size

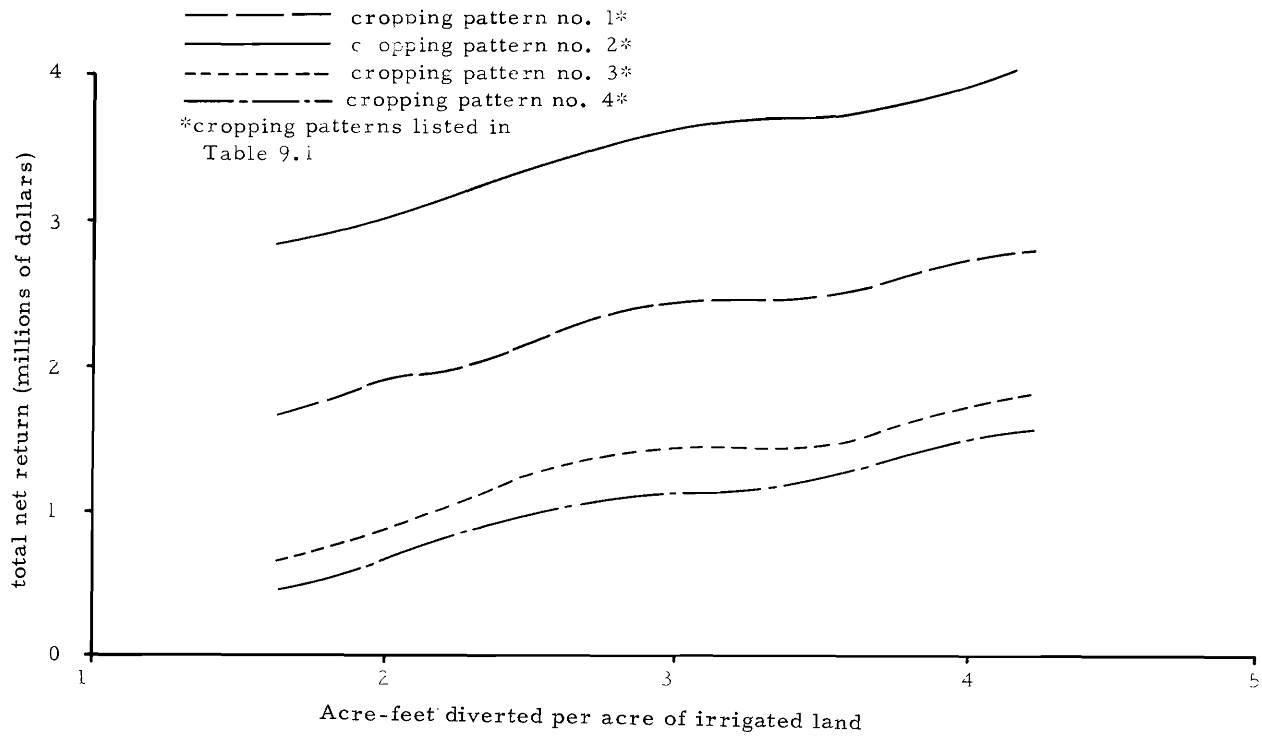

Figure 8.8. Total net return to farm management for various cropping patterns and levels of available irrigation water.

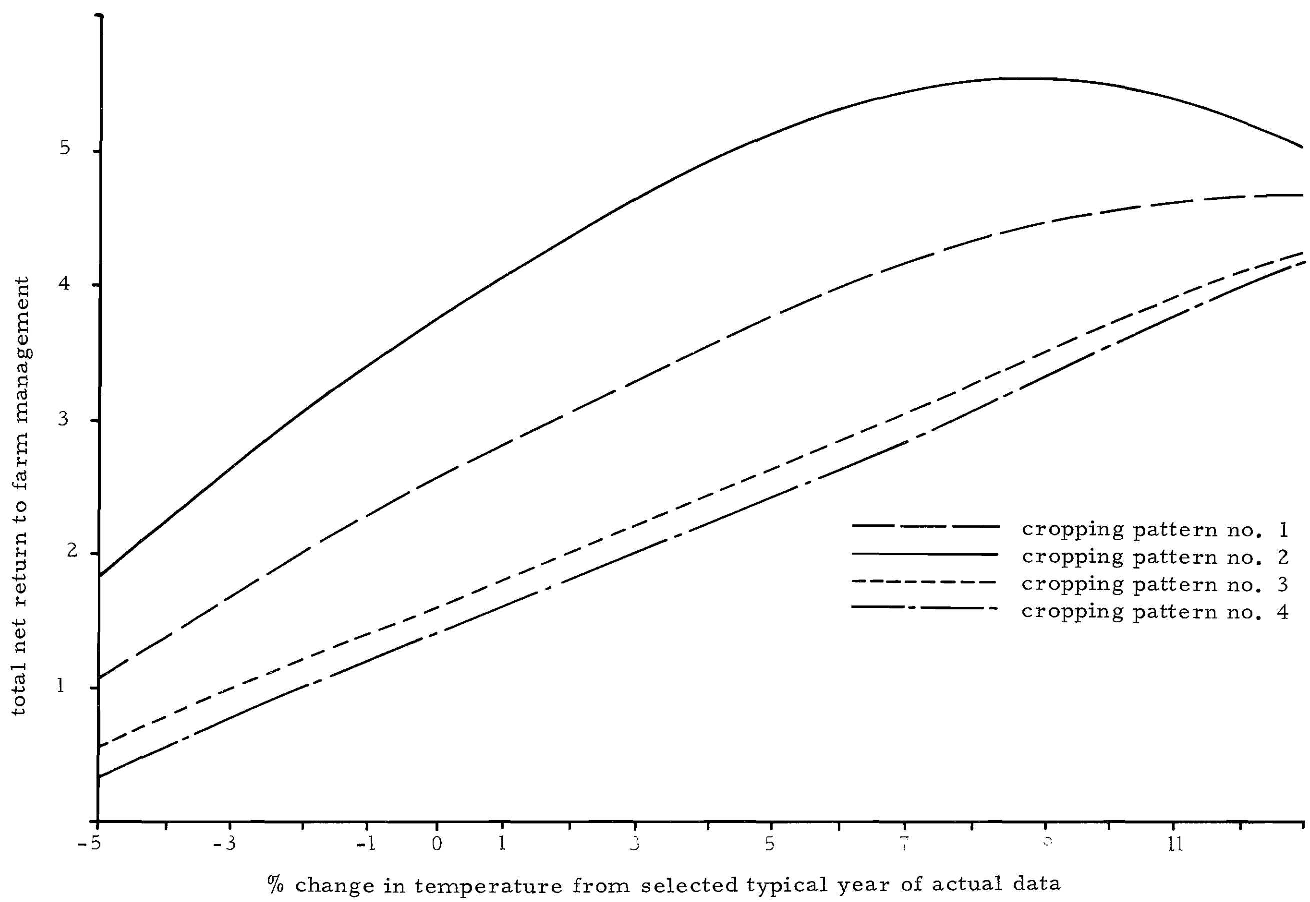

Figure 8.9. Total net farm income as it is related to different levels of temperature.

of farm, equipment available and required for each crop, expected crop prices, labor requirement, and many more. The most profitable cropping pattern will vary from year to year as these conditions vary. If the only criteria is to maximize net farm income, the selection of a cropping pattern for the given conditions will be relatively easy. An example of an investigation with several cropping patterns is shown in Figure 8.8.

Evaluating reservoir storage quantities. The hydrologic problems associated with the design of storage reservoirs include the selection of reservoir capacity appropriate for the demand and available water. Such projects reduce the variability of water supply from year to year and increase the supply of water every year. Evaluation of such projects is normally a very difficult and expensive task. The simulation model will make it possible to test many alternatives and observe the increase in net return associated with each configuration. Construction of storage projects will have such long term effects as allowing higher value crops which require more water to be grown. A study such as that shown in Figure 8.8 could be used to determine the increase in net return attributable to an increase in water supply.

Evaluating water exports and imports. Nature has not distributed man's water resources exactly as he desires. Frequently, there are areas with an excess of water neighbored by areas which are not able to meet the water demands. Often it can be mutually beneficial to the areas involved to consider the possibility of exporting water from one basin to another.

An export equivalent to a certain reduction in normal canal diversion could be related to a particular loss in net return (Figure 8.8). This would be a starting point in evaluating the price tag to place on such water exports. For water years above or below normal, the values would be different for the same amount of water. Also the values would be different for other long-run conditions. All of these things and many more can be taken into consideration and evaluated by proper application of a hydrologic-economic simulation model.

Evaluating the effects of technological advances. Progress in technology has been a dominant influence in an ever increasing per acre yield of agricultural production. Greater use of commercial fertilizer, for example, has been responsible for increases in crop yield. Also improvements in irrigation, pest control, machinery, and soil and water conservation practices have continually upgraded and increased farm production.

Some improvements in technology do not increase yield but have the same effect by reducing costs such as storage and harvesting losses. Increased efficiency in getting water to the farm plus proper management on the farm can bring much saving of this valuable resource. Better seed varieties have been developed which not only give improved yields and quality but are capable of using more fertilizer.

How much more can technology be expected to increase yields? Of course, there must be some physical limit to the production from an acre of land. However, as long as technological progress is promoted through research, an increase in the efficiency of agricultural inputs with respect to outputs can be expected. Such technological advancements can be easily included in this model whether they are from past experience or future predictions. Thus, many continuous years of records can be modeled.

CHAPTER IX

SUMMARY AND CONCLUSIONS

Skilled planning and careful management are essential to achieve the level of efficiency in water use which will be required in the future. Planning in the true sense of the word is a complex and continuing operation. Water resources in ever increasing quantities are continually being sought for competing uses. Especially in the semi-arid southwest, water is the key to the present and future economy. Complex hydrologic and economic factors require a systematic approach which is both interdisciplinary and comprehensive.

Evaluation of several planning alternatives in the past has been difficult because techniques available to test alternative projects were time consuming and expensive. Without the computer, alternatives were limited to two or three modifications of one basic plan. With modern computers, truly comprehensive planning has been made possible.

This report presents a hydrologic-economic simulation model, and demonstrates its application for management and planning within the context of an agriculture based economy. The hydrologic and economic systems are closely interrelated in any water resources project. The amount of water available for plant use is one of the most critical factors in determining crop growth and yield. The study defines the relationship of water to crop yield assuming that other factors of agricultural production are maintained at given levels. Comprehensive planning is difficult if the two systems are analyzed independently because of the many ways in which changes in one system can be reflected in the other system. The advantage of a joint model is that these interrelationships, as in the prototype, are incorporated into a single system.

Data from Cache Valley were used to test and verify the mathematical relationships used in this study. Flow records at the outlet of the valley provided data for quantitative verification of the hydrologic scheme. The economic system was verified with limited information on crop yield as a function of seasonal evapotranspiration. From this information needed crop production functions were estimated for the study area. A successful simulation model of the hydrologic-economic scheme represents a step toward the comprehensive simulation of complex water resource systems. With the verified hydrologic-economic model, several management alternatives are evaluated to determine the best possible management practices. In addition, sensitivity studies in terms of certain selected parameters are described. Construction of contemplated structures or implementation of management decisions can be analyzed quickly and easily by application of the model to various alternatives.

In general, decisions regarding water resource planning and development are made at the following three levels:

1. Project design
2. Project evaluation
3. Project operation

Simulation analysis has a place at all levels, but the greatest potential is realized in application at the last two levels. Through simulation it is possible to evaluate many alternative combinations of the available factors of production. Since there are an infinite number of possible alternatives, simulation alone does not automatically provide an optimum solution. However, by increasing the number of alternatives which can be examined, simulation makes it possible to approach optimum solutions.

Under this study a single model of the hydrologic and economic flow systems is developed. The primary link between the two systems are functions which relate seasonal crop evapotranspiration to yields. For testing, the model is applied to an actual hydrologic unit, and the practical utility of this technique is demonstrated. Typical of the answers which the model is capable of providing are the following:

1. The crop acreage combination which will achieve maximum overall net return for a year of predicted short water supply.
2. The relative efficiency of water with respect to production or net return for several management alternatives or cropping schemes.
3. The value, to the farm unit, of an associated increase in water supply due to an increase in the efficiency of conveyance and application of irrigation water or the procurement of additional water.
4. The efficient conjunctive use patterns for all available water supplies.
5. The marginal values of water by attributing costs to all factors of production except water. The net residual return would then be the return to water at various levels.
6. The project design of reservoir capacities and other facilities of a multiple use project on the basis of an appropriate objective function.
7. The implications of various plans for the export and import of water between river basins. The associated gains and losses can be compared to project costs to assess the total impact of such a transfer.

To provide the ever increasing amounts of water which the nation is requiring, more knowledge is needed. Research into water problems is essential to attain the fullest and wisest use of water resources.

New frontiers of knowledge must be explored continually. As water problems increase in complexity, continued emphasis must be placed on studies to guide water management and water policy.

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APPENDIXES

Appendix A

Hydrologic Data for Cache Valley

Table A1. Average monthly precipitation (inches) for the irrigated crop land of Cache Valley.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1944	1.05	.83	1.51	3.07	.97	3.13	.29	.79	.35	.32	2.02	1.10
1945	.28	1.70	1.77	.83	2.76	3.55	.11	1.95	1.64	1.39	2.80	1.80
1931-1963 Ave.	1.59	1.23	1.43	1.68	1.66	1.22	.54	.74	.90	1.22	1.31	1.28

Table A2. Average monthly temperatures (^{o}F) for irrigated lands of Cache Valley.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1944	14.7	25.3	31.3	42.6	53.7	59.0	67.1	65.2	57.2	50.8	30.9	23.6
1945	24.3	30.9	33.6	40.8	53.8	55.1	68.4	66.6	54.1	49.5	30.3	24.3
1931-1965 Ave.	21.5	26.6	34.4	45.2	53.4	60.8	68.4	67.1	58.3	48.2	34.3	26.3

Table A3. Measured surface inflow to Cache Valley (ac-ft), 1944.

	January	February	March	April	May	June	July	August	September	October	November	December
Bear River at Oneida	23,030	23,610	30,550	43,010	30,870	24,960	49,860	52,500	33,970	19,520	23,230	24,380
Mink Creek (below Diversions)	2,190	1,780	114	234	8,200	3,550	87	65	50	428	1,820	2,390
Mink Creek Diversion					6,788	10,499	7,061	4,497	3,736			
Battle Creek	96	104	150	323	90	147	40	4	11	100	100	100
Weston Creek (below Diversions)	200	191	444	342	209	280	238	129	122	200	200	200
Weston Creek Diversions				200	400	600	400	300	200			
Cub River (below Diversions)	1,230	897	1,310	5,090	16,900	12,370	170	122	123	203	339	816
Cub River Diversions					2,083	5,351	6,001	3,401	2,275			
Maple Creek	250*	500*	1,200*	3,000*	4,300*	1,800*	420*	150*	90*	100*	100*	190*
Little Bear (below Diversions)	2,770	2,480	2,970	9,720	14,560	5,590	980	663	720	1,480	2,330	2,300
Little Bear Diversions					1,241	6,918	9,174	6,729	5,419			
Logan River (above most diversions)	6,560	5,630	5,720	8,760	26,660	27,360	15,280	10,670	8,170	7,450	6,500	5,720
Blacksmith Fork	4,080	3,530	3,860	5,530	9,190	6,530	5,340	4,630	4,030	4,240	4,110	3,710
Clarkston Creek	311	307	336	591	268	550	917	174	27	91	65	44
High Creek	450*	650*	1,000*	1,900	5,360	6,380	1,900	970	668	700*	700*	700*
Cherry Creek	100*	100*	200*	30*	1,180	1,630	250	85	30	50*	50*	100*
Summit Creek	700*	800*	900*	1,940	5,000	4,100	1,600	770	470	400*	400*	700*
Totals	41,967	40,579	48,754	80,670	133,299	118,615	99,718	85,859	60,111	34,962	39,944	41,350

*Estimated values

Annual Total 825,828

Table A4. Measured surface inflow to Cache Valley (ac-ft), 1945.

	January	February	March	April	May	June	July	August	September	October	November	December
Bear River at Oneida	21,620	26,210	34,890	47,330	49,010	51,800	41,380	41,410	29,730	31,800	29,740	33,820
Mink Creek below Diversions	2,250	1,480	454	607	8,140	15,360	548	242	681	3,160	3,100	3,240
Mink Creek Diversions				5,317	9,542	9,129	9,630	6,053	3,903			
Battle Creek	100*	100*	160*	350*	100*	150*	50*	10*	10*	120*	120*	120*
Weston Creek below Diversions				250	600	900	1,200	1,000	600			
Weston Creek Diversions				250	450	650	450	350	250			
Cub River below Diversions	982	1,440	1,530	4,290	16,280	18,460	612	323	401	215	501	2,000
Cub River Diversions				1,357	3,374	5,686	8,286	3,876	2,708			
Maple Creek	300*	590*	1,510*	3,200*	5,000*	2,200*	480*	180*	110*	120*	120*	230*
Little Bear below Diversions	2,370	3,430	4,570	10,910	21,170	14,120	1,930	1,450	1,940	3,260	3,790	4,690
Little Bear Diversions					3,040	7,236	10,770	7,432	4,787			
Logan River (above most Diversions)	5,580	5,140	5,580	7,280	27,920	38,920	23,580	14,290	11,020	9,580	8,510	7,790
Blacksmith Fork	3,580	3,700	4,330	5,570	11,610	12,310	7,060	6,180	5,320	5,240	5,060	5,060
Clarkston Creek	0	0	1,410	0	382	1,060	1,240	416	884	0	0	1,340
High Creek	500*	700*	1,100*	1,320	5,920	8,170	2,770	1,100	696	700*	700*	700*
Cherry Creek	100*	100*	200*	320	1,410	2,000	485	120	45	50*	50*	100*
Summit Creek	700*	800*	800*	1,420	4,640	5,860	2,000	910	640	600*	600*	700*
Totals	38,082	43,690	56,534	89,771	168,788	194,011	112,471	85,342	63,225	54,845	52,291	59,790

* Estimated Values

Annual Total = 1,018,840

Table A5. Crop growth stage coefficients, k_c, used in this model for the various crops.

Crop	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Beets	.25	.25	.25	.25	.35	.66	1.10	1.25	1.14	.25	.25	.25
Corn	.25	.25	.25	.25	.37	.75	1.08	1.03	.65	.25	.25	.25
Grain	.25	.25	.25	.26	.50	1.54	1.12	.25	.25	.25	.25	.25
Alfalfa	.63	.73	.86	.98	1.08	1.13	1.11	1.06	.98	.90	.78	.64
Pasture	.48	.58	.74	.86	.90	.93	.91	.91	.86	.79	.64	.52
Land Phreatophytes	.70	.70	.75	.81	.89	1.02	1.18	1.28	1.29	1.19	1.04	.86
Water Phreatophytes	.70	.70	.75	.81	.89	1.02	1.18	1.28	1.29	1.19	1.04	.86
Water Surface	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table A6. Values of the climatic coefficient, k_t, 1/ for various mean air temperatures, t.

t °F	k_t	t °F	k_t	t °F	k_t
36	.309	61	.741	86	1.174
37	.326	62	.759	87	1.191
38	.343	63	.776	88	1.208
39	.361	64	.793	89	1.226
40	.378	65	.810	90	1.243
41	.395	66	.828	91	1.260
42	.413	67	.845	92	1.278
43	.430	68	.862	93	1.295
44	.447	69	.880	94	1.312
45	.464	70	.897	95	1.330
46	.482	71	.914	96	1.347
47	.499	72	.932	97	1.364
48	.516	73	.949	98	1.381
49	.534	74	.966	99	1.399
50	.551	75	.984	100	1.416
51	.568	76	1.001		
52	.586	77	1.018		
53	.603	78	1.035		
54	.620	79	1.053		
55	.638	80	1.070		
56	.655	81	1.087		
57	.672	82	1.105		
58	.689	83	1.122		
59	.706	84	1.139		
60	.724	85	1.156		

1/ Values of k_t are based on the formula, $k_t = .0173\ t - .314$. For mean temperatures less than 36°, use $k_t = .300$.

Table A7. Monthly percentage of daytime hours (p) of the year for latitudes 18^{o} to 65^{o} north of the equator.

Latitude North	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
65° ---------	3.45	5.14	7.90	9.92	12.65	14.12	13.66	11.25	8.55	6.60	4.12	2.64
64° ---------	3.75	5.30	7.93	9.87	12.42	13.60	13.31	11.15	8.58	6.70	4.35	3.04
63° ---------	4.01	5.40	7.95	9.83	12.22	13.22	13.02	11.04	8.60	6.79	4.55	3.37
62° ---------	4.25	5.52	7.99	9.75	12.03	12.91	12.79	10.92	8.50	6.86	4.72	3.67
61° ---------	4.46	5.61	8.01	9.71	11.88	12.63	12.55	10.84	8.55	6.94	4.89	3.93
60° ---------	4.67	5.70	8.05	9.66	11.72	12.39	12.33	10.72	8.57	7.00	5.04	4.15
59° ---------	4.81	5.78	8.05	9.60	11.61	12.23	12.21	10.60	8.56	7.07	5.09	4.31
58° ---------	4.99	5.85	8.06	9.55	11.44	12.00	12.00	10.56	8.56	7.13	5.13	4.55
57° ---------	5.14	5.93	8.07	9.51	11.32	11.77	11.87	10.47	8.54	7.19	5.27	4.69
56° ---------	5.29	6.00	8.10	9.45	11.20	11.67	11.69	10.40	8.52	7.25	5.54	4.89
55° ---------	5.39	6.06	8.12	9.41	11.11	11.53	11.59	10.32	8.51	7.30	5.62	5.01
54° ---------	5.53	6.12	8.15	9.36	11.00	11.40	11.43	10.27	8.50	7.33	5.74	5.17
53° ---------	5.64	6.19	8.16	9.32	10.88	11.31	11.34	10.19	8.52	7.38	5.83	5.31
52° ---------	5.75	6.23	8.17	9.28	10.81	11.13	11.22	10.15	8.49	7.40	5.94	5.43
51° ---------	5.87	6.25	8.21	9.26	10.76	11.07	11.13	10.05	8.48	7.41	5.97	5.46
50° ---------	5.98	6.32	8.25	9.25	10.69	10.93	10.99	10.00	8.44	7.43	6.07	5.65
48° ---------	6.13	6.42	8.22	9.15	10.50	10.72	10.83	9.92	8.45	7.56	6.24	5.86
46° ---------	6.30	6.50	8.24	9.09	10.37	10.54	10.66	9.82	8.44	7.61	6.38	6.05
44° ---------	6.45	6.59	8.25	9.04	10.22	10.38	10.50	9.73	8.43	7.67	6.51	6.23
42° ---------	6.60	6.66	8.28	8.97	10.10	10.21	10.37	9.64	8.42	7.73	6.63	6.39
40° ---------	6.73	6.73	8.30	8.92	9.99	10.08	10.24	9.56	8.41	7.78	6.73	6.53
38° ---------	6.87	6.79	8.34	8.90	9.92	9.95	10.10	9.47	8.38	7.80	6.82	6.66
36° ---------	6.99	6.86	8.35	8.85	9.81	9.83	9.99	9.40	8.36	7.85	6.92	6.79
34° ---------	7.10	6.91	8.36	8.80	9.72	9.70	9.88	9.33	8.36	7.90	7.02	6.92
32° ---------	7.20	6.97	8.37	8.72	9.63	9.60	9.77	9.28	8.34	7.93	7.11	7.05
30° ---------	7.30	7.03	8.38	8.72	9.53	9.49	9.67	9.22	8.34	7.99	7.19	7.14
28° ---------	7.40	7.02	8.39	8.68	9.46	9.38	9.58	9.16	8.32	8.02	7.27	7.27
26° ---------	7.49	7.12	8.40	8.64	9.37	9.30	9.49	9.10	8.32	8.06	7.36	7.35
24° ---------	7.58	7.17	8.40	8.60	9.30	9.19	9.41	9.05	8.31	8.10	7.43	7.46
22° ---------	7.76	7.22	8.41	8.57	9.22	9.12	9.31	9.00	8.30	8.13	7.50	7.56
20° ---------	7.73	7.26	8.40	8.52	9.14	9.02	9.25	8.95	8.30	8.19	7.58	7.88
18° ---------	7.88	7.26	8.40	8.46	9.66	8.99	9.20	8.81	8.29	8.24	7.67	7.89

Appendix B

Analog Computer Output

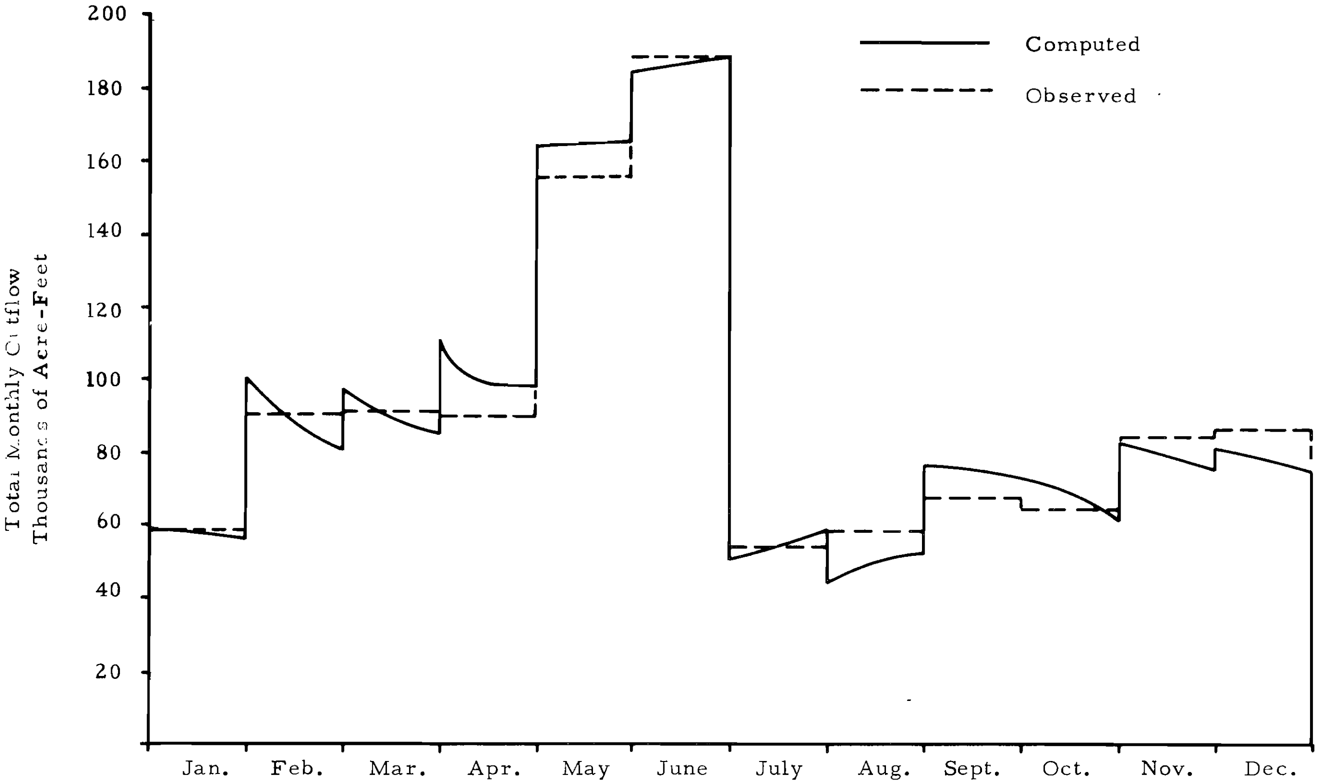

Figure B1. Typical analog computed and observed monthly outflow (acre-feet) for Cache Valley, 1945.

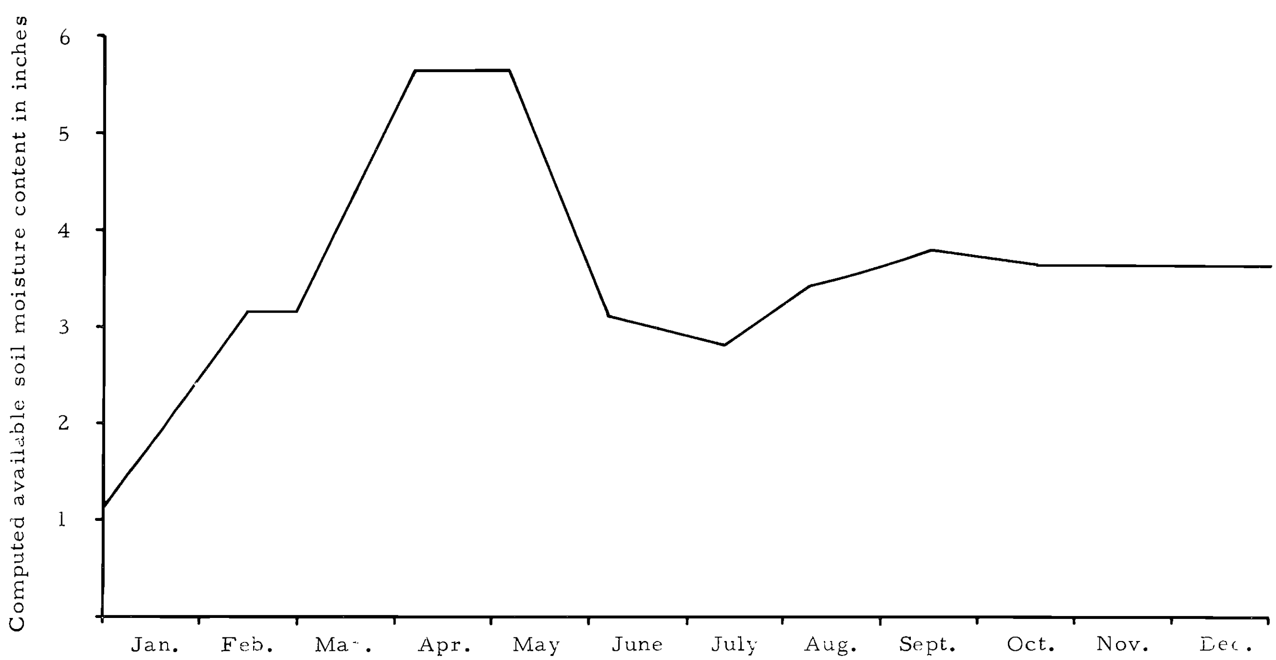

Figure B2. Analog computed available soil moisture content in incnes, 1945.

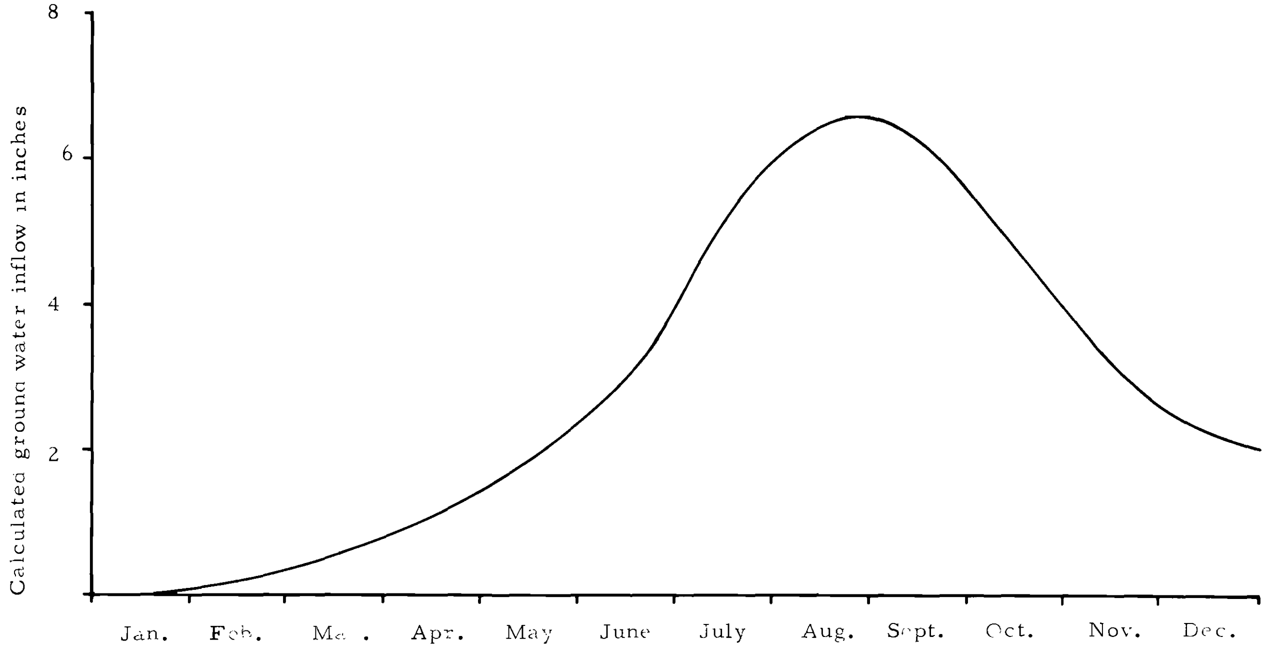

Figure B3. Analog calculated groundwater inflow (in inches over the entire area), 1945.

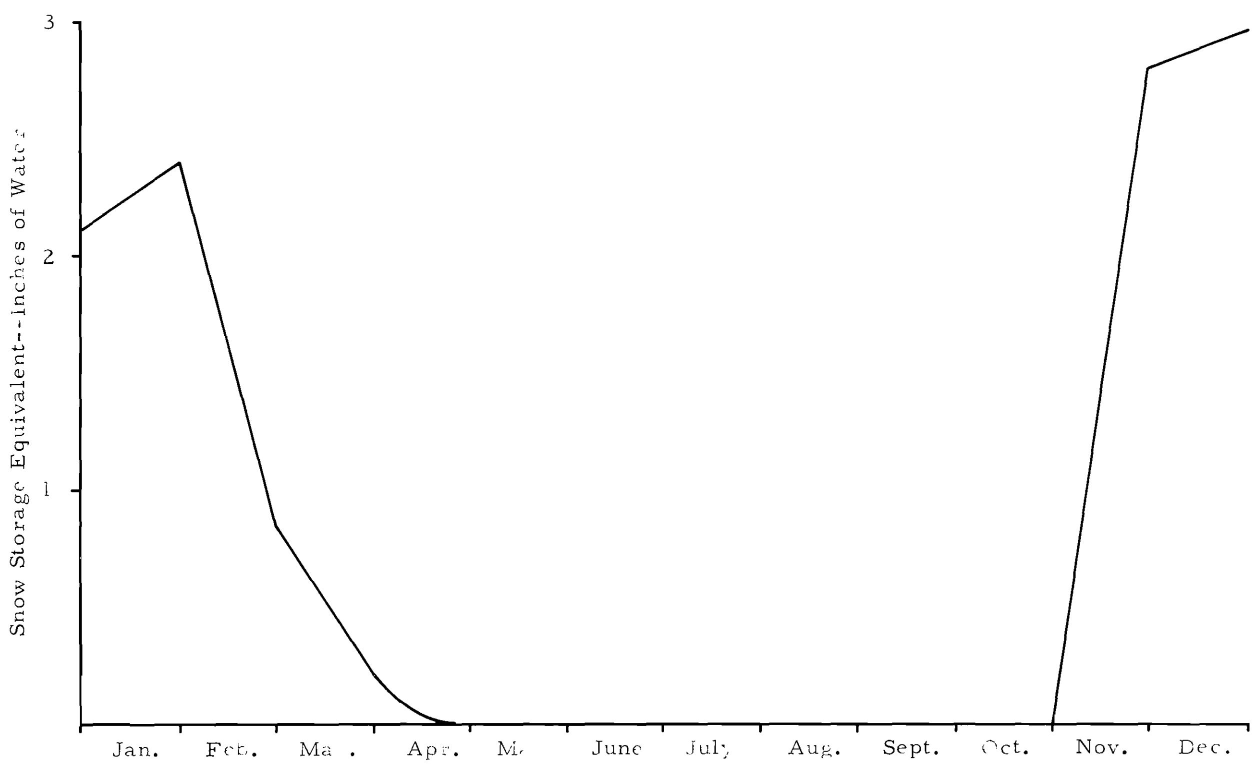

Figure B4. Analog computed snow storage equivalent (in inches over the entire area), 1945.

Appendix C

Economic Data for Cache Valley

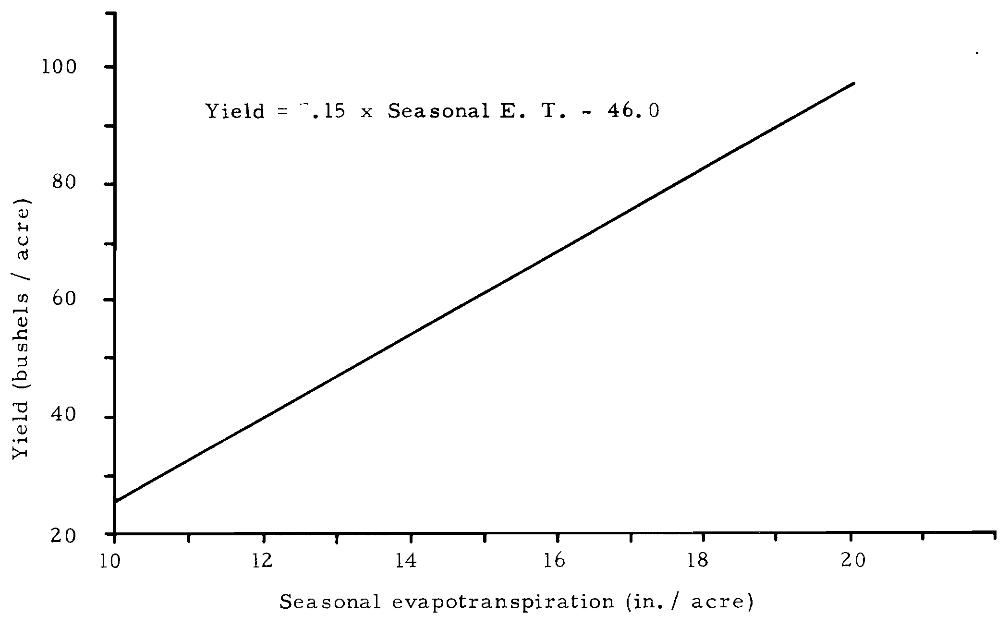

Figure C1. Seasonal evapotranspiration--yield relationship for barley.

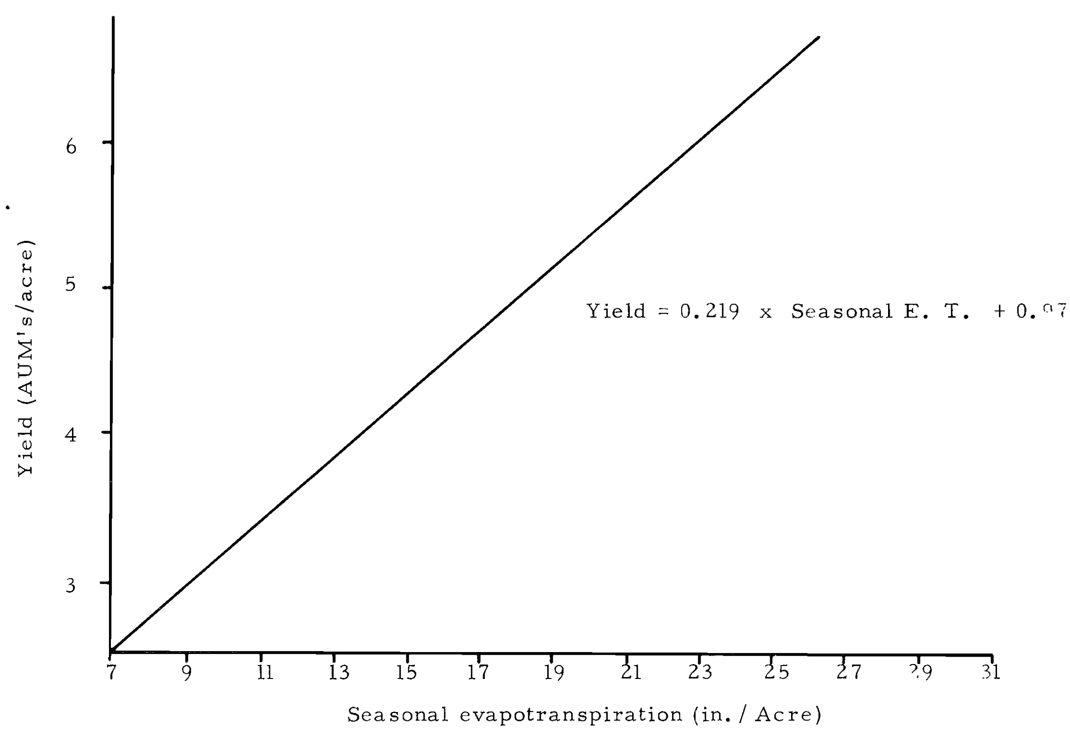

Figure C2. Seasonal evapotranspiration--yield relationship for pasture.

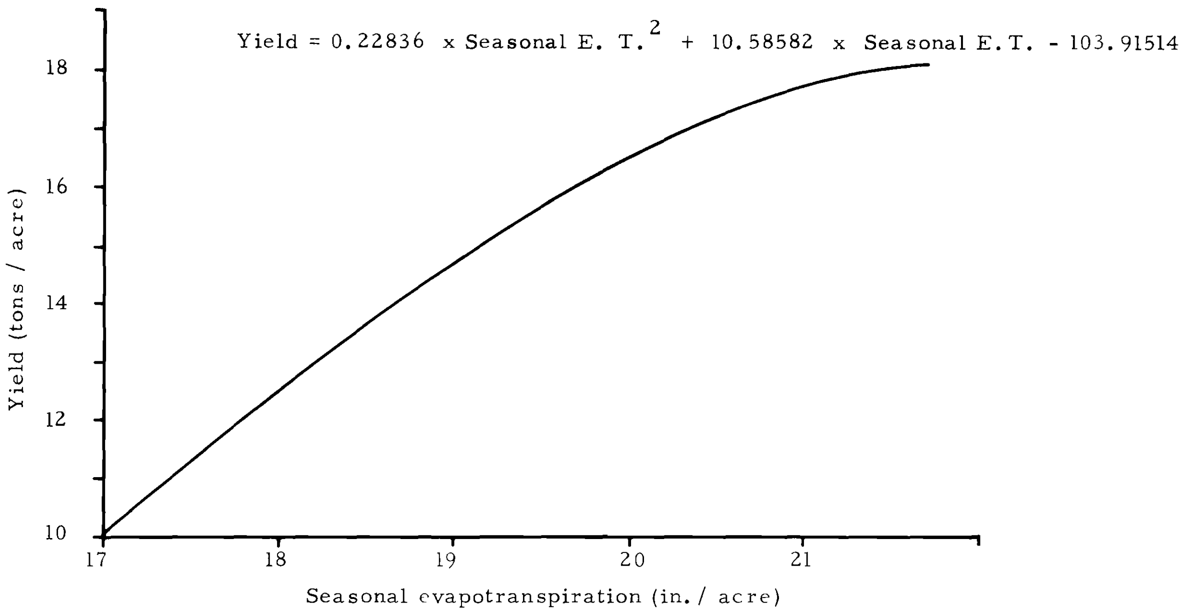

Figure C3. Seasonal evapotranspiration--yield relationship for sugar beets.

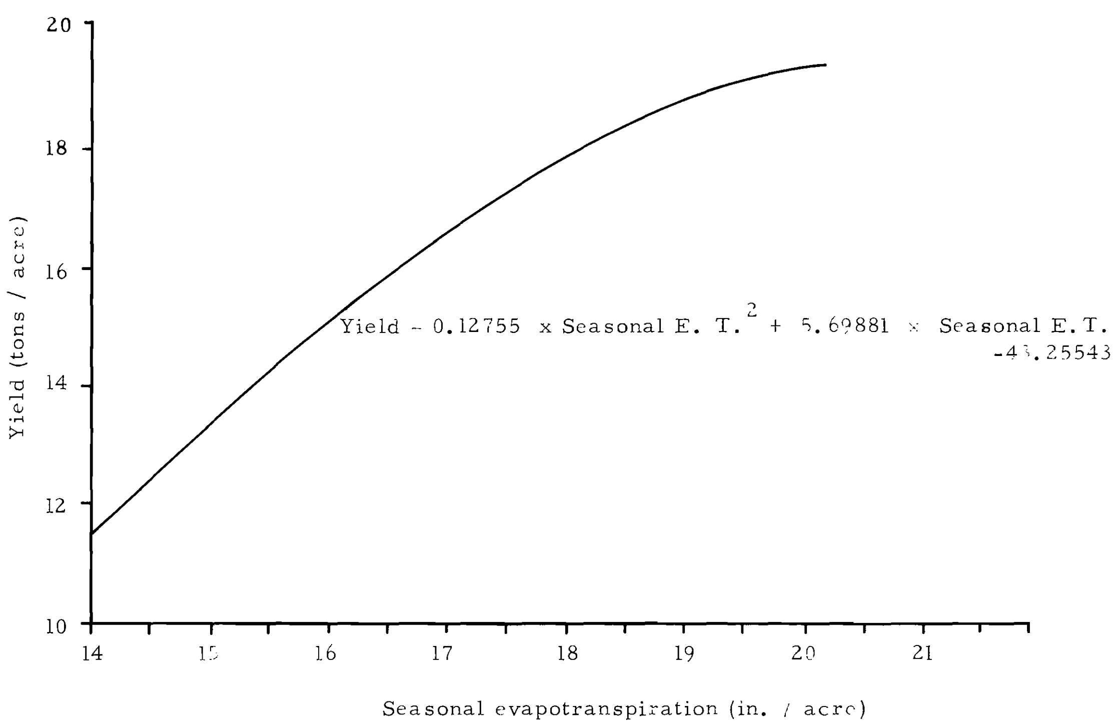

Figure C4. Seasonal evapotranspiration--yield relationship for corn silage.

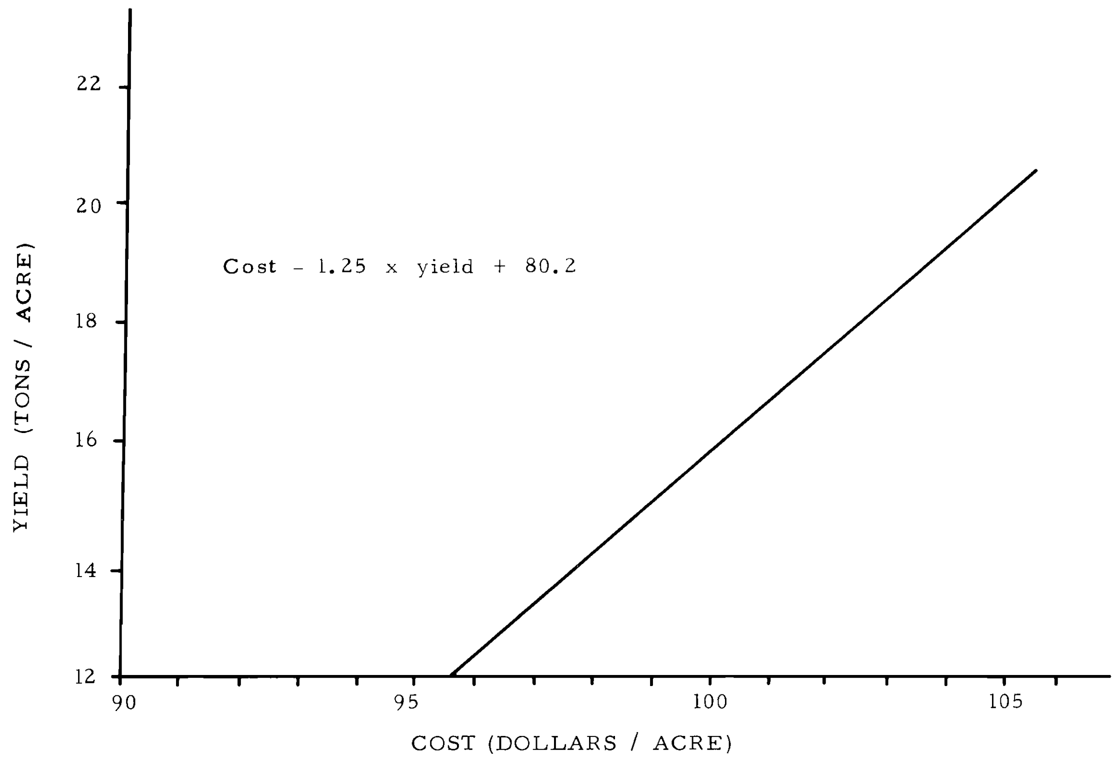

Figure C5. Cost--yield relationship for corn silage.

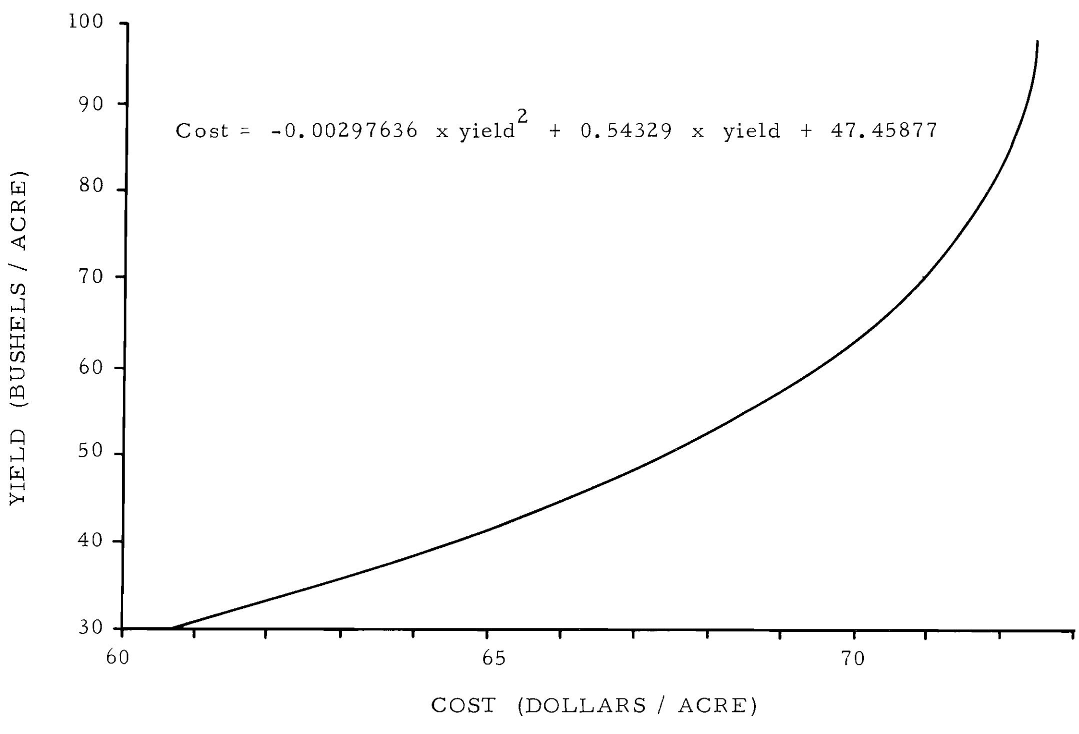

Figure C6. Cost--yield relationship for barley.

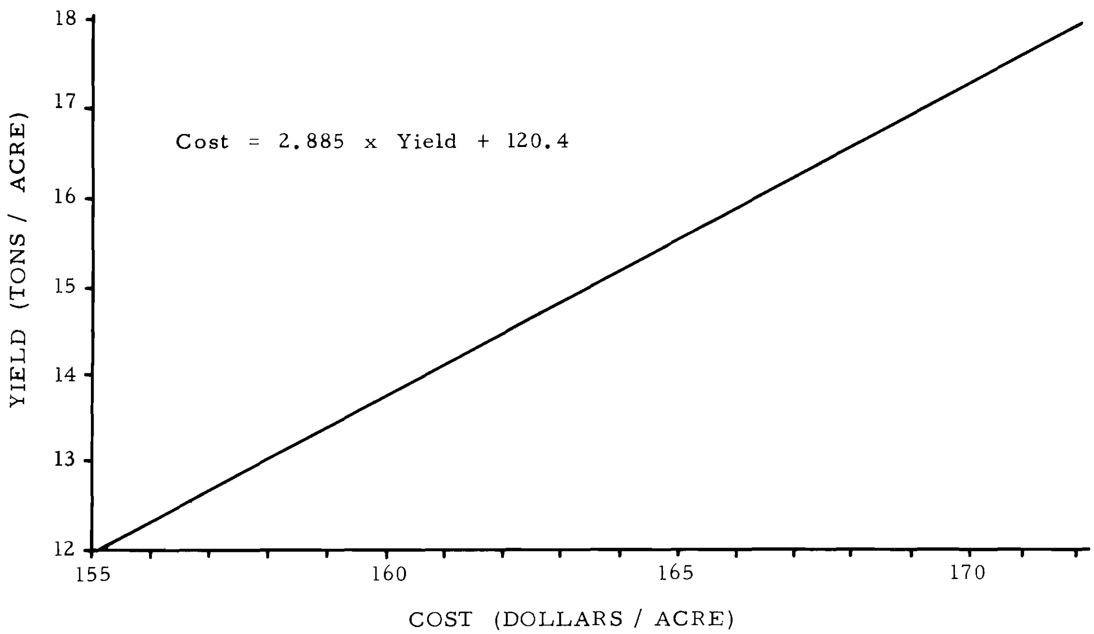

Figure C7. Cost--yield relationship for sugar beets.

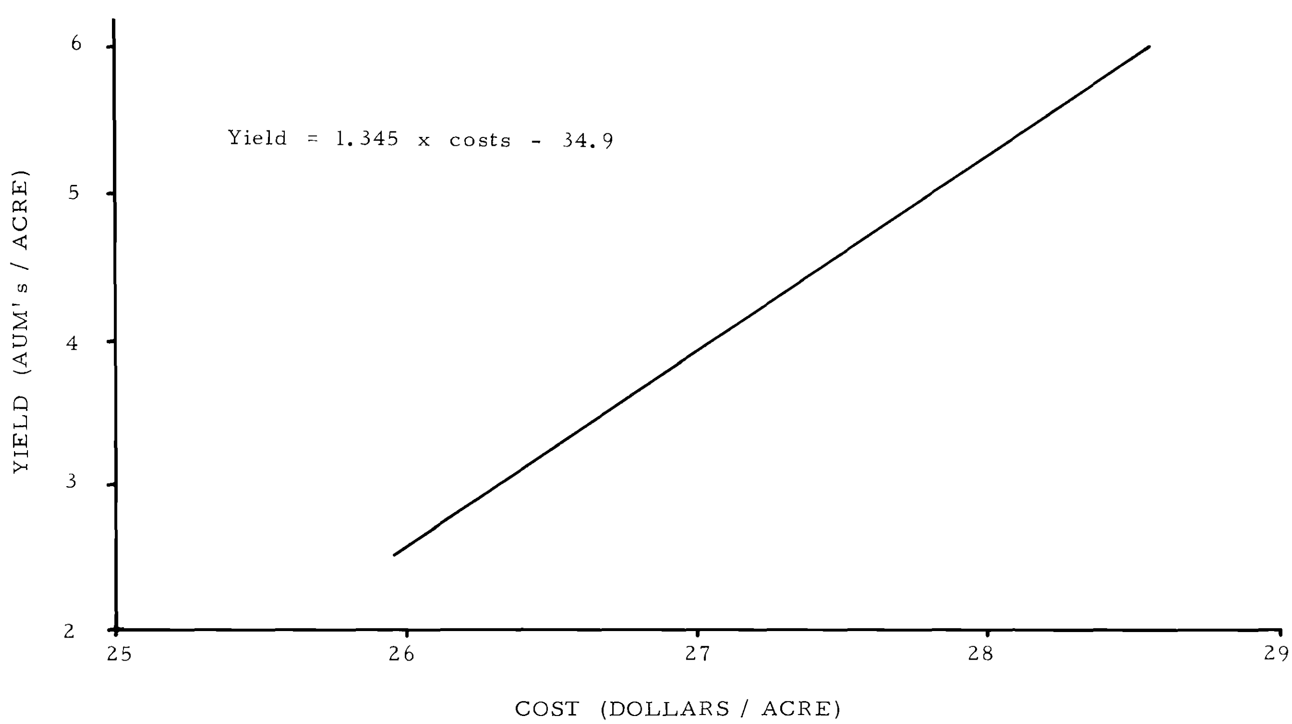

Figure C8. Cost--yield relationship for pasture.

Table C1a. Typical costs of corn silage production.[1]

Input	Quantity of Input	Per Unit	Per Farm	Per Acre
Tractor	5.11 hr/ac.	1.69/hr.	172.80	8.64
Plow	20 ac.	.90/ac.	18.00	.90
Level 2X	20 ac.	.23/ac.	9.20	.46
Harrow 2X	20 ac.	.07/ac.	2.80	.14
Cultivate 3X	20 ac.	.87/ac.	52.20	2.61
Drill (Hired)	20 ac.	2.50/ac.	50.00	2.50
Ditcher	20 ac.	.23/ac.	4.60	.23
Fert. Spreader	20 ac.	.35/ac.	7.00	.35
Truck (Owned)	1010 mi.	.16/mi.	161.60	8.08
Fertilizer	20 ac.	11.25/ac.	225.00	11.25
Water	20 ac.	5.28/ac.	123.20	5.28
Interest on Investment	20 ac.	30.00/ac.	600.00	30.00
Interest on Operating Capital	20 ac.	.74/ac.	14.80	.74
Chopper w/Tractor (Hired)	20 ac.	.75/T.	270.00	13.50
Truck (Hired)	20 ac.	3.50/ac.	70.00	3.50
Taxes	20 ac.	4.00/ac.	80.00	4.00
Pickup & Auto Cost		7.50/ac.	150.00	7.50
Seed	20 ac.	3.75/ac.	75.00	3.75

[1] Based on a cropped area of 20 acres with an assumed yield of 18 tons per acre.

Table C1b. Estimated net return for corn silage production at various levels of yield.

Gross Income ($7.00/ton)	20 Tons	18 Tons	16 Tons	14 Tons	12 Tons
	140.00	126.00	112.00	98.00	84.00
	104.93	103.43	100.80	97.92	94.79
Net Income/Acre	35.07	22.57	11.20	.08	-10.79

Table C2a. Typical costs of sugar beets production.[1]

Input	Quantity of Input	Per Unit	Per Farm	Per Acre
Plow	20 ac.	.90/ac.	18.00	.90
Cultivate 5X	20 ac.	.87/ac.	87.00	4.35
Truck	1010 mi.	.16/mi.	161.60	8.08
Fertilizer Spreader 2X	20 ac.	.35/ac.	14.00	.70
Level 2X	20 ac.	.23/ac.	9.20	.46
Harrow 4X	20 ac.	.07/ac.	5.60	.28
Ditcher	20 ac.	.23/ac.	4.60	.23
Drill (Hired)	20 ac.	2.50/ac.	50.00	2.50
Topping (Hired)	16 T.	1.75/ac.	560.00	28.00
Fertilizer	20 ac.	20.00/ac.	400.00	20.00
Seed	20 ac.	2.25/ac.	45.00	2.25
Water	20 ac.	5.72/ac.	;;4/40	5.72
Thinning	20 ac.	20.00/ac.	400.00	20.00
Howing	20 ac.	12.00/ac.	240.00	12.00
Interest on Investment	20 ac.	6% of 500.00	600.00	30.00
Tractor	7.56 hr/ac.	169/ac.	279.20	12.77
Truck (Hired)	40% of crop	100/T.	128.00	6.40
Interest on Operating Capital	20 ac.	3.02/ac.	60.40	3.02
Pickup & Auto Cost				9.25
				166.91

[1] Based on a cropped area of 20 acres with an assumed yield of 18 tons per acre.

Table C2b. Estimated net return for sugar beet production at various levels of yield.

Gross Income/Acre	18 Tons	17 Tons	16 Tons	15 Tons	14 Tons	13 Tons	12 Tons
$16.60/ Ton	298.80	282.20	265.60	249.00	232.40	215.80	199.20
Value of Tops	8.00	8.00	8.00	8.00	8.00	7.00	6.00
	306.80	290.20	273.60	257.00	240.40	222.80	205.20
Costs/Acre	171.91	169.41	166.91	163.97	161.03	158.09	155.15
Net Income/Acre	134.89	120.79	106.69	93.03	79.37	64.71	50.05

Table C3a. Typical costs of small grains production.[1]

Input	Quantity of Input	Costs of Input	Costs Per Farm	Cost Per Acre
Tractor	2.86 hr/ac.	1.69/hr.	144.90	4.83
Plow	30 ac.	.90/ac.	27.00	.90
Harrow	30 ac. 3X	.07/ac.	6.30	.21
Level	30 ac. 2X	.23/ac.	13.80	.46
Fertilizer Spreader	30 ac.	.35/ac.	10.50	.35
Grain Drill	30 ac.	.90/ac.	27.00	.90
Ditcher	30 ac.	.23/ac.	6.90	.23
Sprayer	30 ac.	.40/ac.	12.00	.40
Truck	375 mi.	.16/mi.	60.00	2.00
Combine (Hired)	30 ac.	6.50/ac.	195.00	6.50
Spray (1 pt./ac. Amine 24D)	30 ac.	.40/ac.	12.00	.40
Seed	30 ac.	4.00/ac.	120.00	4.00
Fertilizer	30 ac.	7.00/ac.	240.00	7.00
Water	30 ac.	4.00/ac.	120.00	4.00
Interest on Capital	6% on 500.00/ac.	30.00/ac.	900.00	30.00
Taxes	30 ac.	4.00/ac.	120.00	4.00
Interest on Operating Capital	30 ac.	.43/ac.	12.90	.43
Pickup & Car costs				4.00
Total costs/acre				70.61

[1] Based on a cropped area of 30 acres with an assumed yield of 18 tons per acre.

Table C3b. Estimated net return for small grains production at various levels of yield.

Variable Income	100 Bu.	90 Bu.	80 Bu.	70 Bu.	60 Bu.	50 Bu.	40 Bu.	30 Bu.
Barley at 1.05/Bu.	105.00	94.50	84.00	73.50	63.00	52.50	42.00	31.50
Straw	5.40	4.80	4.20	3.60	3.00	2.40	---	---
Pasture	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	111.40	100.30	89.20	78,10	67.00	55.90	43.00	32.50

Variable Costs	100 Bu.	90 Bu.	80 Bu.	70 Bu.	60 Bu.	50 Bu.	40 Bu.	30 Bu.
Water	4.00	4.00	4.00	4.00	3.08	2.20	1.32	0
Fertilizer	7.00	7.00	7.00	7.00	7.00	7.00	5.00	3.00
Harvest	8.50	7.50	7.50	6.50	6.50	5.50	5.50	4.50
Seed	4.00	4.00	4.00	4.00	4.00	4.00	3.50	3.00
Interest on Operating Capital	.43	.43	.43	.43	.43	.43	.35	.28
Total	23.93	22.93	22.93	21.93	21.01	19.13	15.67	10.78
	+ 2.00	+ 1.00	+ 1.00	0	- .92	- 2.80	- 6.26	- 9.82
	70.61	70.61	70.61	70.61	70.61	70.61	70.61	70.61
	+ 2.00	+ 1.00	+ 1.00	0	- .92	- 2.80	- 6.26	- 9.82
Total Costs	72.61	71.61	71.61	70.61	69.69	67.81	64.35	60.79
Gross Income	111.40	100.30	89.20	78.10	67.00	55.90	43.00	32.50
Total Costs/Acre	72.61	61.71	61.61	70.61	69.69	67,81	64.35	60.79
Net Income per Acre	38.79	28.69	17.59	7.49	- 2.69	-11.91	-21.35	-28.29

Table C4a. Typical costs of pasture production.[1]

Input	Cost Per Acre
Water	$ 3.94
Ditching	.16
Interest on Investment	15.00
Pickup & Truck	3.00
Taxes	2.50
Fertilizer[2]	2.60
Planting - 7 Year Rotation	1.35
Total Costs/Acre	$28.55

[1] Based on a cropped area of 20 acres with an assumed yield of 6 AUMS per acre.

[2] The levels of fertility application vary with amount of water expected.

Table C4b. Estimated net return for pasture production at various levels of yield.

Receipts-Value of AUM at $5.50	$33.30	$22.00	$13.75
Total Costs	28.55	27.10	25.95
Net Return per Acre	$ 4.45	$-5.10	$-12.20

Appendix D

Digital Computer Program and Output

Table D1. Digital computer program list of symbols.

```
C    HYDROLOGIC SIMULATION MODEL OF CACHE VALLEY
C
C
C    ACCET(I)=ACCUMULATED EVAPOTRANSPIRATION DURRING EACH MONTH (CROP I)
C    ACCSM=ACCUMULATED SNOWMELT DURRING EACH MONTH
C    ADJPP=ADJUSTED PRECIPITATION TO PREVENT SNOWFALL FROM ADDING TO SOIL
C         MOISTURE (INCHES PER ACRE)
C    AKC(I)=MONTHLY VALUES OF KC FOR EACH CROP FOR EVAPORATION
C    AJSM(I)=ADJUSTED SOIL MOISTURE CONTENT FOR CROP I (INCHES PER ACRE)
C    AIR(I)=SEASONAL IRRIGATION WATER APPLIED FOR CROP I
C    AIRI(MO)=IRRIGATION OF CROP I FOR MONTH MO(IN/MONTH)
C    AMIR(I)=IRRIGATION APPLIED TO CROP I FOR A PARTICULAR MONTH
C    APH== FRACTION OF CANAL DIVERSIONS BEING APPLIED TO LAND PHREATOPHYTS
C    APRIC(I)=SELLING PRICE OF CROP I PER UNIT
C    AREIG=IRRIGATED AREA IN ACRES
C    AREA(I)=THE AREA IN ACRES OF CROP I
C    AREAT=TOTAL AREA IN ACRES
C    AW(I)=MAXIMUM AVAILABLE WATER FOR CROP I (INCHES) = RD(I)*WHC(I)
C    AWSKC=KC FOR WATER SURFACE
C    CDP=PERCENT OF CANAL DIVERSIONS WHICH DEEP PERCOLATE TO GROUNDWATER
C    COST(I)=COST IN DOLLARS PER ACRE FOR PRODUCING CROP I
C    CGW=CONSTANT FOR DETERMINING UNGAGED GROUNDWATER INFLOW
C    CKS=CONSTANT FOR SNOWMELT EQUATION
C    CKT=CONSTANT IN EVAPOTRANSPIRATION EQUATION
C    CMELT=SNOWMELT CORRELATION COEFFICIENT
C    CPH=PERCENT OF PHREATOPHYTE EVAPOTRANSPIRATION TAKEN FROM SOIL.
C       (1-CPH=FRACTION OF E.T. FROM RESERVOIR)
C    CSI=PERCENT OF THE SURFACE INFLOW THAT IS ASSUMED TO MAKE UP THE
C         UNMEASURED SURFACE INFLOW
C    DLIRS=CHANGE IN RESERVOIR STORAGE (ACRE-FEET)
C    DPGWI(MO)=GROUNDWATER DELAY LEVEL 1 AFTER LOSING WATER TO SURFACE
C    ETI(MO)=ET OF CROP I FOR MONTH MO(IN)
C    ET(I)=EVAPOTRANSPIRATION FOR EACH CROP (INCHES PER ACRE)
C    ETPHS=EVAPOTRANSPIRATION OF PHREATOPHYTS THAT ARE GROWING ON THE
C         LAND (INCHES PER ACRE)
C    ETPHW=EVAPOTRANSPIRATION OF PHREATOPHYTS THAT ARE GROWING IN WATER
C         (INCHES PER ACRE)
C    GW=DEEP PERCOLITION FROM IRRIGATED LAND (ACRE-FEET)
C    GW(1,2,3)=GROUNDWATER INFLOWS FOR DIFFERENT MONTHS PLUS DEEP
C         PERCOLATION (ACRE-FEET)
C    GWI1=GROUNDWATER IN DELAY LEVEL 1 BEFOR LOSING SOME TO SURFACE
C    GW21(MO)=GROUNDWATER IN DELAY LEVEL 2 FOR THE MONTH
C    GW31(MO)=MONTHLY VALUE OF GROUNDWATER INFLOW PLUS DEEP PERCOLATION
C    GWA(MO)=AMOUNT OF WATER DEEP PERCOLATED TO GROUNDWATER
C    SLUSI=LATE SUMMER UNMEASURED SURFACE INFLOW COEFFICIENT
C    MCT=NUMBER OF MONTHS OF DATA WHICH ARE TO BE CALCULATED
C    MO=MONTH OF YEAR
C    NYR=YEAR OF RECORD TO BEGIN COMPUTATIONS
C    P=MONTHLY PERCENTAGE OF DAYLIGHT HOURS OF THE YEAR
C    PR=PRECIPITATION (INCHES PER ACRE)
C    QC=CANAL DIVERSIONS (ACRE-FEET)
C    QCEFF=PERCENT OF CANAL DIVERSIONS THAT GOES INTO THE SOIL (1-QCEFF
C         IS RETURN FLOW TO RESERVOIR)
C    QCFRT=CANAL DIVERSIONS DIVERTED TO THAT CROP (INCHES PER ACRE)
C    QEF=THE AMOUNT OF CANAL DIVERSIONS WHICH HAS NOT BEEN DIVERTED TO A
C         CROP FOR THAT PARTICULAR MONTH (ACRE-FEET)
C    QIN=THE CURRENT VALUE OF QEF IN INCHES OVER THAT PARTICULAR CROP
C    RD(I)=ROOT DEPTH IOF CROP I (FEET)
C    RETG(I)=GROSS RETURN IN DOLLARS PER ACRE FOR SELLING CROP I
C    RETN(I)=NET RETURN IN DOLLARS PER ACRE OF CROP I
C    RETNV=TOTAL NET RETURN IN DOLLARS FROM THE ENTIRE AREA
C    ROUT=OUTFLOW FROM THE VALLEY (ACRE-FEET)
C    S=THE STORAGE COEFFICIENT WHICH DETERMINES HOW FAST THE WATER WILL COME FROM
C         THE GROUND WATER RESERVOIR INTO THE SURFACE RESERVOIR (S=1 WOULD MEAN
C         THAT IT WOULD COME DIRECTLY INTO THE SURFACE RESERVOIR EACH MONTH.
C         DELAYED BUT NOT SMOOTHED)
C    SGWI=S*GWI
C    SI=MEASURED SURFACE INFLOW (ACRE-FEET)
C    SMAX=THE MAXIMUM AMOUNT OF SOIL MOISTURE THAT CAN BE HELD AGAINST
C         GRAVITY FOR EACH CROP (NOT SATURATED) IN INCHES PER ACRE
C    SMELT=SNOWMELT IN TERMS OF WATER EQUIVALENT (INCHES PER ACRE)
C    SMES=LIMITING ROOT ZONE AVAILABLE MOISTURE CONTENT BELOW WHICH THE
C         ACTUAL EVAPOTRANSPIRATION RATE BECOMES LESS THAN THE POTENTIAL
C         RATE (INCHES PER ACRE)
C    SM(I)=QUANTITY OF WATER STORED WITHIN THE ROOT ZONE AND AVAILABLE
C         FOR PLANT USE (I=1,6 REPRESENTING THE STORAGE FOR EACH
C         CROP) MEASURED IN INCHES PER ACRE
C    TA=MEAN SURFACE AIR TEMPERATURE IN DEGREES F
C    TDTRS=NET ANNUAL CHANGE IN RESERVOIR STORAGE
C    TET1=ANNUAL E. T. OF BEETS
C    TET2=ANNUAL E. T. OF CORN
C    TET3=ANNUAL E. T. OF GRAIN
C    TET4=ANNUAL E. T. OF ALFALFA
C    TET5=ANNUAL E. T. OF PASTURE
C    TET6=ANNUAL E. T. OF LAND-BASED PHREATOPHYTS
C    TETPH=ANNUAL E.T. OF WATER-BASED PHREATOPHYTS
C    TIRR=TOTAL SEASONAL IRRIGATION IN ACRE-FEET
C    TPR=ANNUAL PRECIPITATION
C    TGWA=TOTAL ANNUAL WATER ENTERING GROUNDWATER
C    TGWA=ANNUAL DEEP PERCOLATION
C    UGWA(MO)=TOTAL AMOUNT OF WATER ENTERING DELAY LEVEL 3 FOR THE MONTH
C    TGW3=ANNUAL GROUNDWATER INFLOW
C    TOC=ANNUAL CANAL DIVERSIONS
C    TROUT=COMPUTED ANNUAL AREA OUTFLOW
C    TWSET=ANNUAL E.T. OF WATER SURFACE
C    TSGWI=ANNUAL GROUNDWATER THAT COMES TO SURFACE
C    TST=ANNUAL MEASURED SURFACE INFLOW
C    TSMLT=ANNUAL ACCUMULATED SNOWMELT
C    TUSI=ANNUAL UNMEASURED SURFACE INFLOW
C    TWS=ANNUAL ACCUMULATED SNOW STORAGE
C    USTI(MO)=MONTHLY UNGAGED SURFACE INFLOW
C    UGW=UNMEASURED GROUNDWATER INFLOW INTO THE VALLEY (ACRE-FEET)
C    USI=UNMEASURED SURFACE INFLOW (ACRE-FEET)
C    WHC(I)=AVAILABLE WATER HOLDING CAPACITY OF SOIL FOR CROP I (INCHES
C         OF WATER PER FOOT OF SOIL)
C    WS=SNOW STORAGE IN TERMS OF WATER EQUIVALENT (INCHES PER ACRE)
C    WSAR=WATER SURFACE AREA (A-F)
C    WSET=EVAPOTRANSPIRATION FROM WATER SURFACE (INCHES PER ACRE)
C    YET(I)=THE ACCUMULATED SEASONAL EVAPOTRANSPIRATION FOR CROP I
C         DURRING THE GROWING SEASON
C    YIELD(I)=THE YIELD OF CROP I PER ACRE. IN THE REGULAR UNITS OF
C         MEASUREMENT FOR THAT CROP
```

Table D2. Flow diagram of digital program.

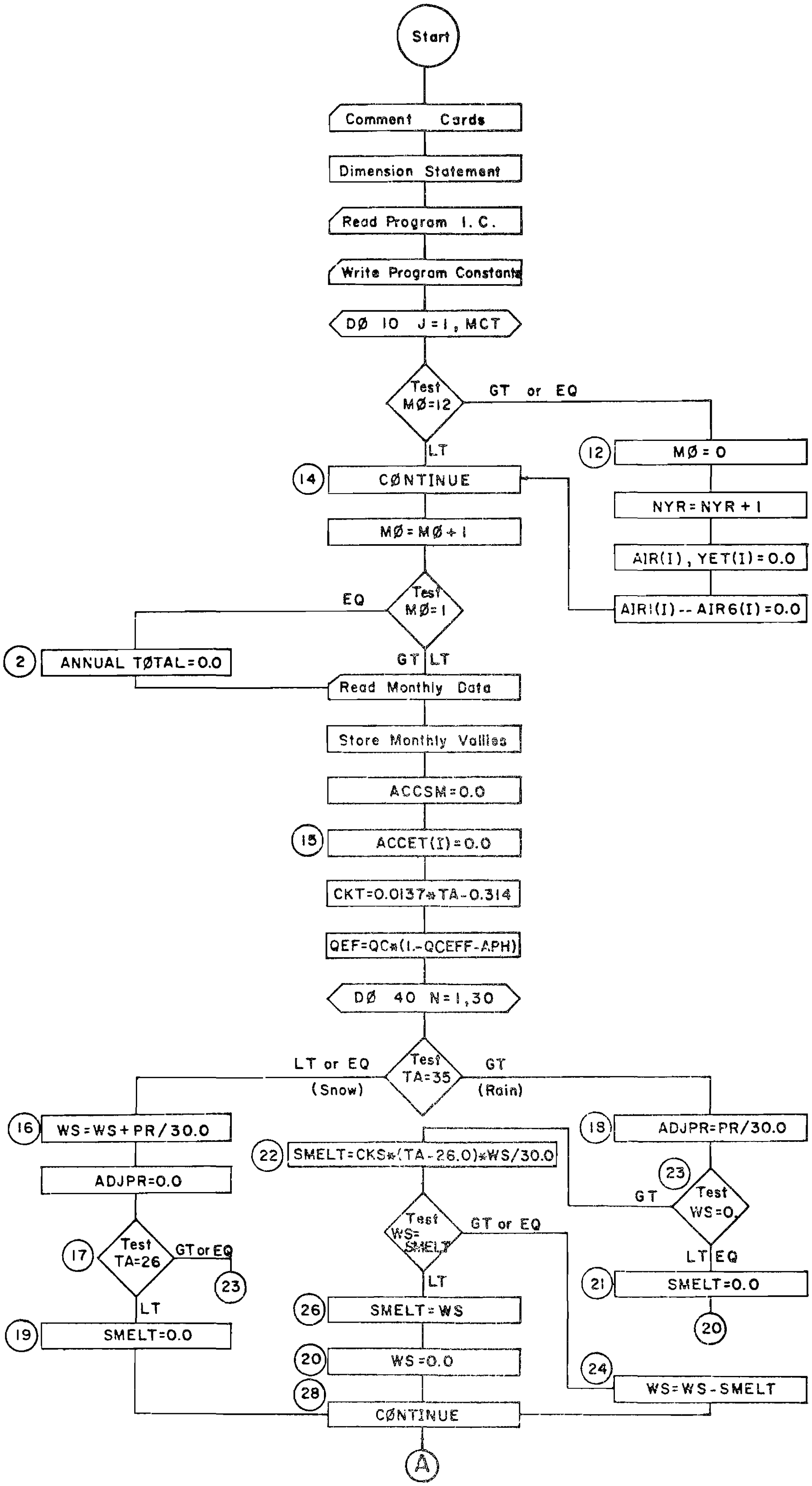

Table D2. Continued.

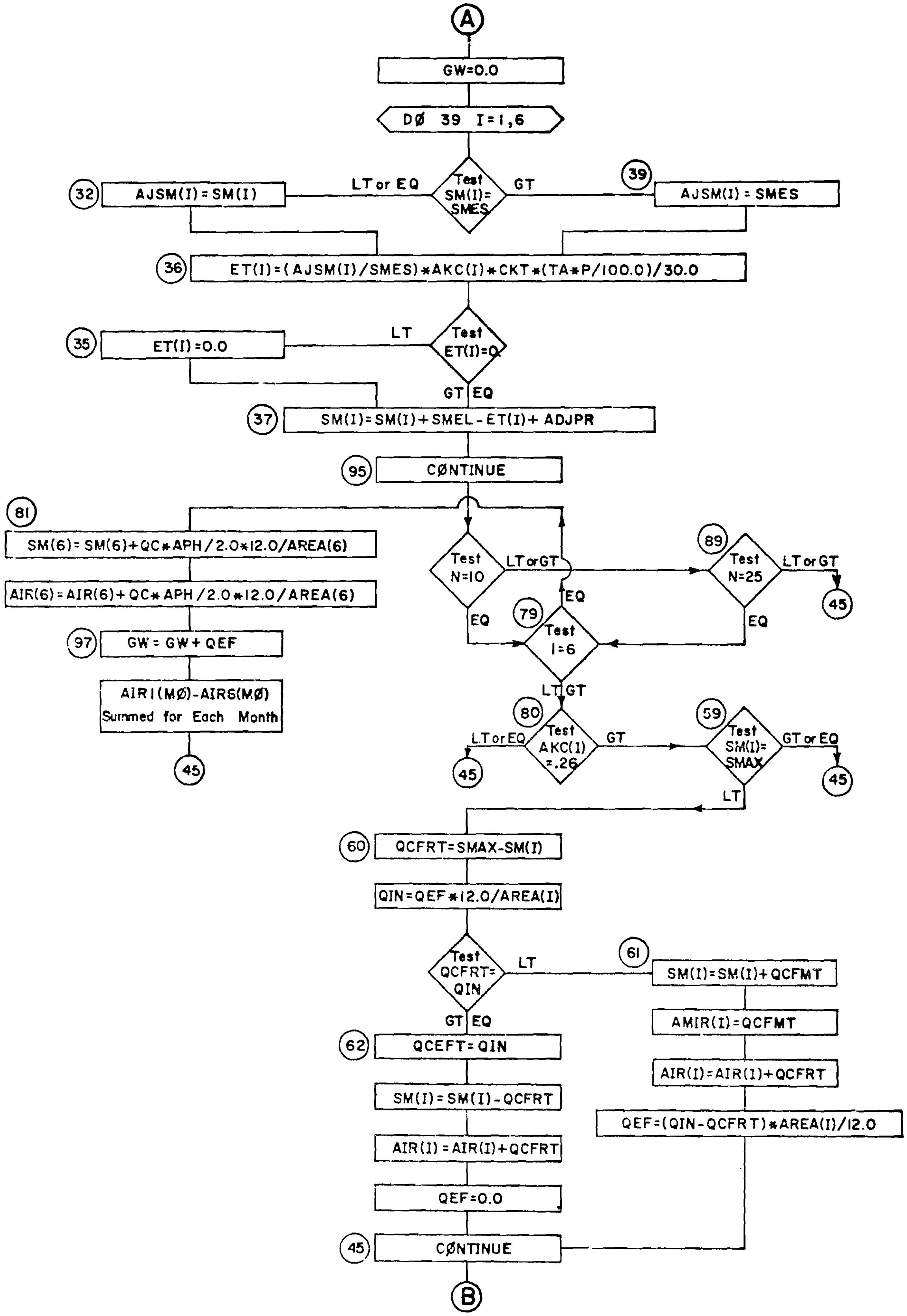

Table D2. Continued.

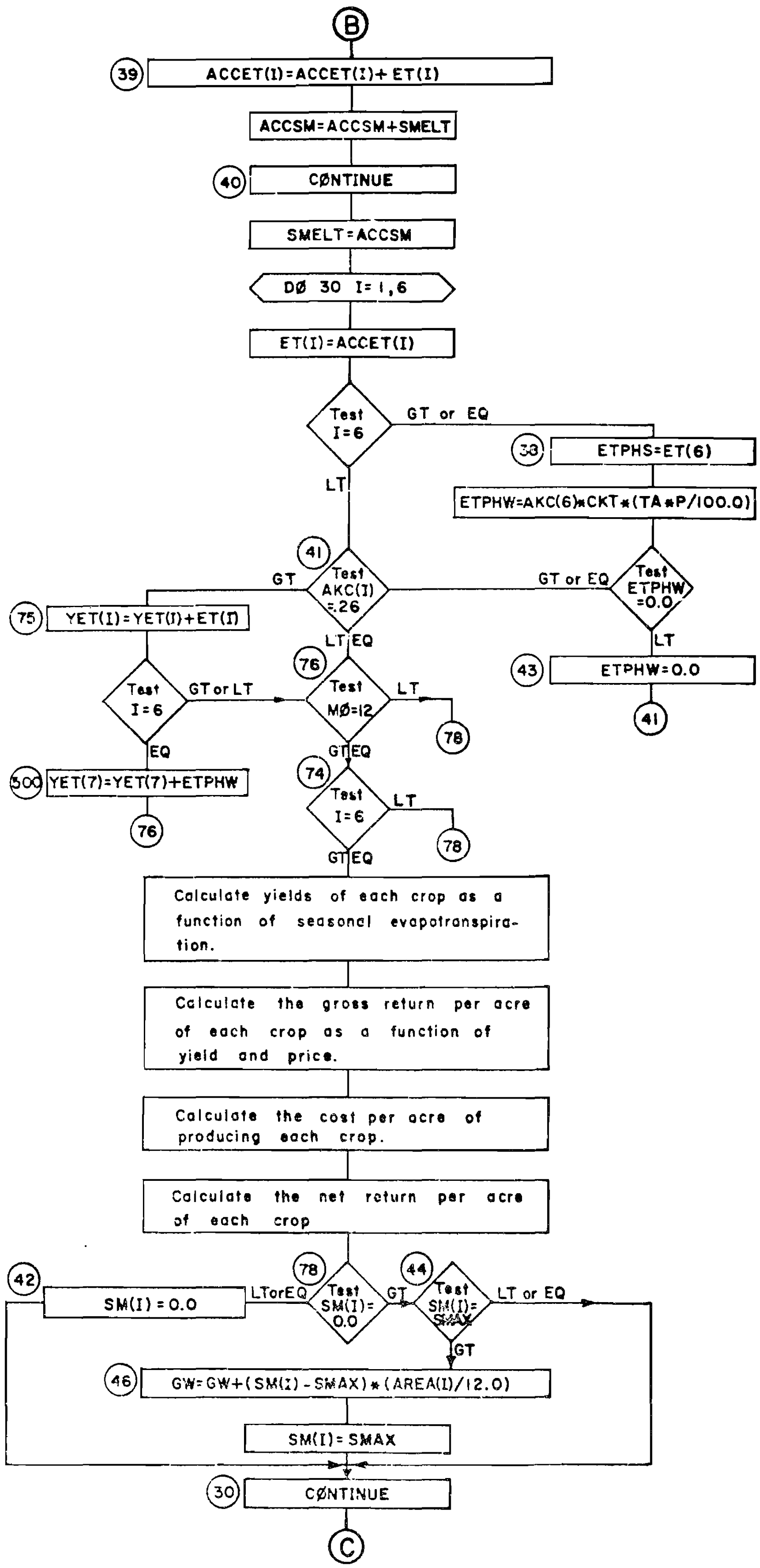

Table D2. Continued.

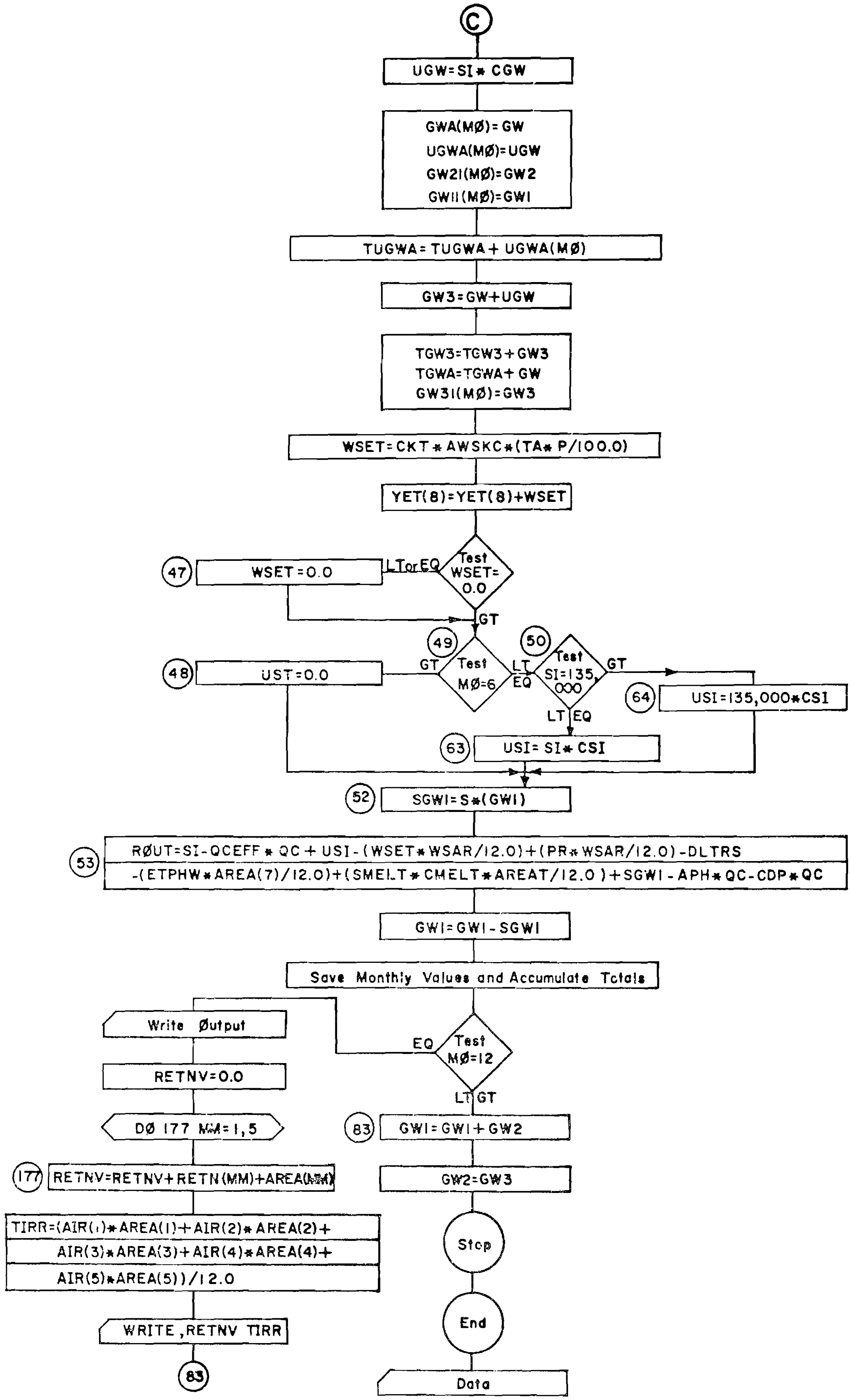

Table D3. Digital computer program listing for the hydrologic-economic model.

```
C
C
C
      DIMENSION PR1(13),TA1(13),SI1(13),QC1(13),P1(13),DTRS1(13),AK1(13)
     1,AK2(13),AK3(13),AK4(13),AK5(13),AK6(13),ROUT1(13),WS1(13),
     2SMLT1(13),ET1(13),ET2(13),ET3(13),ET4(13),ET5(13),ET6(13),
     3WSET1(13),SM1(13),SM2(13),SM3(13),SM4(13),SM5(13),SM6(13),
     4SGW11(13),ETPH1(13),GW31(13),AMIR(8),
     5USI1(13),AKC(7),SM(7),AJSM(7),ACCET(7),AREA(7),ET(7),
     6YET(9),APRIC(7),YIFLD(7),RETG(7),COST(7),RETN(7),AIR(9),
     7GWA(13),UGWA(13),GW21(13),GW11(13),DPGW1(13),AIR1(13),AIR2(13),
     8AIR3(13),AIR4(13),AIR5(13),AIR6(13),RD(7),WHC(7),AW(7)
      READ(5,110) AREA(1),AREA(2),AREA(3),AREA(4),AREA(5),AREA(6),
     1AREA(7),AREIG,AREAT
      READ(5,140)APRIC(1),APRIC(2),APRIC(3),APRIC(4),APRIC(5)
      READ(5,112)RD(1),RD(2),RD(3),RD(4),RD(5),RD(6),WHC(1),WHC(2),
     1WHC(3),WHC(4),WHC(5),WHC(6)
      DO 141 IN=1,12
  141 READ(5,103)AK1(IN),AK2(IN),AK3(IN),AK4(IN),AK5(IN),AK6(IN)
    9 MO=0
      READ(5,100) NYR,MCT,WS,CSI,CMELT,GW1,GW2,CKS,SMES,CPH,QCEFF,
     1CGW,AWSKC,CDP
      READ(5,101) SM(1),SM(2),SM(3),SM(4),SM(5),SM(6),S,WSAR,APH,SLUSI
  100 FORMAT(2I5,3F5.2,2F5.0,7F5.2)
  101 FORMAT(6F5.1,F5.2,F5.0,2F5.2)
  110 FORMAT(9F8.0)
  140 FORMAT(5F6.2)
  112 FORMAT(12F5.1)
  103 FORMAT(6F6.2)
      DO 113 IK=1,6
  113 AW(IK)=RD(IK)*WHC(IK)
      WRITE(6,250)
      WRITE(6,251)CSI
      WRITE(6,252)CMELT
      WRITE(6,253)GW1
      WRITE(6,254)GW2
      WRITE(6,255)CKS
      WRITE(6,256)WS
      WRITE(6,260)CGW
      WRITE(6,262)QCEFF
      WRITE(6,263)SMES
      WRITE(6,264)APH
      WRITE(6,265)CDP
  250 FORMAT(1H ,'HYDROLOGIC INITIAL CONDITIONS')
  251 FORMAT(1H0,'CSI=UNMEASURED SUR INFLOW CORR COEFF=',F5.2)
  252 FORMAT(1H ,'CMELT=SNOWMELT CORRELATION COEFF=',F5.2)
  253 FORMAT(1H ,'GW1=GW INITIAL CONDITION IN LEVEL 1 (AF)=',F8.0)
  254 FORMAT(1H ,'GW2=GW INITIAL CONDITION IN LEVEL 2 (AF)=',F8.0)
  255 FORMAT(1H ,'CKS=SNOWMELT EQUATION CONSTANT=',F5.2)
  256 FORMAT(1H ,'WS=SNOW STORAGE AT BEGINNING OF PERIOD (IN)=',F5.2)
  260 FORMAT(1H ,'CGW=UNGAGED GROUNDWATER INFLOW CONSTANT=',F5.2)
  262 FORMAT(1H ,'QCEFF=PERCENT CANAL DIV ACTUALLY USED BY CROPS=',F5.2)
  263 FORMAT(1H ,'SMES=LOWER LIMIT OF SOIL MOIST FOR POT ET(IN)=',F5.2)
  264 FORMAT(1H ,'APH=FRACTION OF CANAL DIV WHICH GO TO LD PHYTS=',F5.2)
  265 FORMAT(1H ,'CDP=PERCENT OF CANAL DIVERSIONS WHICH DEEP PERCOLATE T
     1O GROUNDWATER=',F5.2)
C
C
      DO 10 J=1,MCT
C
C        SYSTEM FOR COMPUTING THE MONTH AND YEAR
C
      IF(MO-12) 14,12,12
   12 MO=0
      NYR=NYR+1
      DO 4 I=1,6
      AIR(I)=0.
    4 YET(I)=0.
      DO 5 I=1,12
      AIR1(I)=0.
      AIR2(I)=0.0
      AIR3(I)=0.0
      AIR4(I)=0.0
      AIR5(I)=0.0
    5 AIR6(I)=0.0
   14 CONTINUE
      MO=MO+1
      IF(MO-1)1,2,1
    2 TSI=0.0
      TPR=0.0
      TQC=0.0
      TDTRS=0.0
      TROUT=0.0
      TUGWA=0.0
      TSMLT=0.0
      TET1=0.0
      TET2=0.0
      TET3=0.0
      TET4=0.0
      TET5=0.0
      TET6=0.0
      TETPH=0.0
      TGWA=0.0
      TGW3=0.0
      TUSI=0.0
      TWSET=0.0
      TSGW1=0.0
    1 CONTINUE
      DO 6 I=1,6
    6 AMIR(I)=0.
      READ(5,102) PR,TA,SI,QC,P,DLTRS
  102 FORMAT(F10.2,F10.1,2F10.0,F10.2,F10.0)
      PR1(MO)=PR
      TA1(MO)=TA
      SI1(MO)=SI
      QC1(MO)=QC
      P1(MO)=P
      DTRS1(MO)=DLTRS
      AKC(1)=AK1(MO)
      AKC(2)=AK2(MO)
      AKC(3)=AK3(MO)
      AKC(4)=AK4(MO)
      AKC(5)=AK5(MO)
      AKC(6)=AK6(MO)
```

Table D3. Continued.

```
C
C       CALCULATION OF SNOWMELT AND SNOW STORAGE
C
      ACCSM=0.0
      DO 15 I=1,6
   15 ACCET(I)=0.0
      CKT=0.0173*TA-0.314
   17 QEF=(QC*QCEFF)/2.0
      DO 40 N=1,30
      IF(N-25)8,7,8
    7 QEF=(QC*QCEFF)/2.0
    8 CONTINUE
      IF(TA-35.0) 16,16,18
   18 ADJPR=PR/30.0
      GO TO 23
   16 WS=WS+PR/30.0
      ADJPR=0.0
   17 IF(TA-26.0) 19,23,23
   23 IF(WS-0.0) 21,21,22
   21 SMELT=0.0
      GO TO 20
   22 SMELT=CKS*(TA-26.0)*WS/30.0
      IF(WS-SMELT) 26,24,24
   26 SMELT=WS
   20 WS=0.0
      GO TO 28
   24 WS=WS-SMELT
      GO TO 28
   19 SMELT=0.0
   28 CONTINUE
      GW=0.0
      DO 39 I=1,6
C
C  I=1,7 REPRESENTS EACH OF THE 7 CROPS
C         CROP(1)=SUGAR BEETS
C         CROP(2)=CORN
C         CROP(3)=SMALL GRAINS
C         CROP(4)=ALFALFA HAY
C         CROP(5)=PASTURE
C         CROP(6)=THE PHREATOPHYTS GROWING ON LAND
C         CROP(7)=THE PHREATOPHYTS GROWING IN WATER
C
C         CALCULATION OF EVAPOTRANSPIRATION
C
      IF(SM(I)-SMES) 32,32,34
   32 AJSM(I)=SM(I)
      GO TO 36
   34 AJSM(I)=SMES
   36 ET(I)=(AJSM(I)/SMES)*AKC(I)*CKT*(TA*P/100.0)/30.0
      IF(ET(I)-0.0) 35,37,37
   35 ET(I)=0.0
   37 SM(I)=SM(I)+SMELT-ET(I)+ADJPR
   95 CONTINUE
C
C
C  PROGRAM TO APPLY IRRIGATION WATER TO CROPS ON A PRIORITY BASIS
C        (TO STATEMENT 45)
C
      IF(N 10)39,79,89
   89 IF(N-25)45,79,45
   79 CONTINUE
      IF(I-6)80,81,80
   81 SM(6)=SM(6)+((QC*APHI/2.0)*12.0/AREA(6)
      AMIR(6)=((QC*APHI/2.0)*12.0/AREA(6)
      AIR(6)=AIR(6)+AMIR(6)
      GO TO 97
   80 IF(AKC(I)-.26)45,45,59
   59 IF(SM(I)-AW(I))60,45,45
   60 QCFRT=AW(I)-SM(I)
      QIN=QEF*12.0/AREA(I)
      IF(QCFRT-QIN) 61,62,62
   61 SM(I)=SM(I)+QCFRT
      AMIR(I)=QCFRT
      AIR(I)=AIR(I)+QCFRT*(1.0/QCEFF)
      QEF=(QIN-QCFRT)*AREA(I)/12.0
      GO TO 45
   62 QCFRT=QIN
      SM(I)=SM(I)+QCFRT
      AIR(I)=AIR(I)+QCFRT*(1.0/QCEFF)
      AMIR(I)=QCFRT
      QEF=0.0
      GO TO 45
   97 GW=GW+QEF
   33 AIR1(MO)=AIR1(MO)+AMIR(1)*(1.0/QCEFF)
      AIR2(MO)=AIR2(MO)+AMIR(2)*(1.0/QCEFF)
      AIR3(MO)=AIR3(MO)+AMIR(3)*(1.0/QCEFF)
      AIR4(MO)=AIR4(MO)+AMIR(4)*(1.0/QCEFF)
      AIR5(MO)=AIR5(MO)+AMIR(5)*(1.0/QCEFF)
      AIR6(MO)=AIR6(MO)+AMIR(6)*(1.0/QCEFF)
      DO 96 MP=1,6
   96 AMIR(MP)=0.
C
C
   45 CONTINUE
C
   39 ACCET(I)=ACCET(I)+ET(I)
      ACCSM=ACCSM+SMELT
   40 CONTINUE
      SMELT=ACCSM
      DO 30 I=1,6
      ET(I)=ACCET(I)
C
C
C  THIS SECTION IS TO CALCULATE E T,THEN YIELD, THEN NET RETURN PER ACRE
C
C
      IF(I-6) 41,38,38
   38 ETPHS=ET(6)
      ETPHW=AKC(6)*CKT*(TA*P/100.0)
      IF(ETPHW-0.0) 43,41,41
   43 ETPHW=0.0
   41 CONTINUE
      IF(AKC(I)-.26)76,76,75
   75 YET(I)=YET(I)+ET(I)
      IF(I-6)76,500,76
  500 YET(7)=YET(7)+ETPHW
   76 IF(MO-12)78,74,74
   74 IF(I-6)73,72,72
   72 YIELD(1)=-.22836307*YET(1)*YET(1)+10.585824*YET(1)-103.915139
      YIELD(2)=-.12754989*YET(2)*YET(2)+5.6988066*YET(2)-43.255431
      YIELD(3)=7.15*YET(3)-46.0
      YIELD(4)=.117*YET(4)+.73
      YIELD(5)=.219*YET(5)+.97
   73 DO 70 K=1,5
   70 RETG(K)=YIELD(K)*APRIC(K)
      RETG(1)=RETG(1)+8.0
      RETG(3)=RETG(3)-.00067855*YIELD(3)*YIELD(3)+.16749949*YIELD(3)-
     13.6994099
      RETG(4)=RETG(4)+4.50
      COST(1)=2.985*YIELD(1)+120.4
      COST(2)=1.25*YIELD(2)+80.2
      COST(3)=-.00297536*YIELD(3)*YIELD(3)+.54329129*YIELD(3)+47.45877
```

Table D3. Continued.

```
      COST(4)=-.7739237*YIELD(4)*YIELD(4)+10.8945277*YIELD(4)+33.717275
      COST(5)=28.55
      DO 71 K=1,5
   71 RETN(K)=RETG(K)-COST(K)
C
C        CALCULATION OF SOIL MOISTURE AND DEEP PERCOLATION
C
   78 IF(SM(I)-0.0) 42,42,44
   42 SM(I)=0.0
      GO TO 30
   44 IF(SM(I)-AW(I))30,30,46
   46 GW=GW+(SM(I)-AW(I))*(AREA(I)/12.0)
      SM(I)=AW(I)
   30 CONTINUE
C
C        UNGAGED GROUNDWATER INFLOW
C
      GW=GW+CDP*QC
      UGW=ST*CGW
      GWA(MO)=GW
      UGWA(MO)=UGW
      GW21(MO)=GW2
      GW11(MO)=GW1
      TUGWA=TUGWA+UGWA(MO)
C
C        TOTAL GROUNDWATER FOR MONTH
C
      GW3=GW+UGW
      TGW3=TGW3+GW3
      TGWA=TGWA+GW
      GW31(MO)=GW3
C
C        EVAPOTRANSPIRATION FROM WATER SURFACE
      WSET=CKT*AWSKC*(TA*P/100.0)
      YET(8)=YET(8)+WSET
C
C        CALCULATION OF UNGAGED SURFACE INFLOW
C
      IF(WSET-0.0) 47,47,49
   47 WSET=0.0
   49 IF(MO-6) 50,50,48
C
C   STATEMENTS 50-64 CUT THE PEAK OFF THE UNMLASURED SURFACE INFLOW
C
   50 IF(SI-135000.) 63,63,64
   63 USI=SI*CSI
      GO TO 52
   64 USI=135000.*CSI
      GO TO 52
   48 USI=SI*SLUSI
C
C        COMPUTATION OF RESEPVOIR OUTFLOW
C
C
   52 SGW1=S*(GW1)
   53 ROUT=SI-QCFFF*QC+USI-(WSET*WSAR/12.0)+(PR*WSAR/12.0)-DLTRS
     1-(ETPHW*AREA(7)/12.00)+(SMELT*CMELT*AREAT/12.0)+SGW1-APH*QC-CDP*QC
      GW1=GW1-SGW1
      DPGW1(MO)=GW1
      ROUT1(MO)=ROUT
      WS1(MO)=WS
      SMLT1(MO)=SMELT
      ET1(MO)=ET(1)
      ET2(MO)=ET(2)
      ET3(MO)=ET(3)
      ET4(MO)=ET(4)
      ET5(MO)=ET(5)
      ET6(MO)=ET(6)
      WSET1(MO)=WSET
      SM1(MO)=SM(1)
      SM2(MO)=SM(2)
      SM3(MO)=SM(3)
      SM4(MO)=SM(4)
      SM5(MO)=SM(5)
      SM6(MO)=SM(6)
      SGW11(MO)=SGW1
      USI1(MO)=USI
      ETPH1(MO)=ETPHW
      TSI=TSI+SI1(MO)
      TPR=TPR+PR1(MO)
      TQC=TQC+QC1(MO)
      TDTRS=TDTRS+DTRS1(MO)
      TROUT=TROUT+ROUT1(MO)
      TSMLT=TSMLT+SMLT1(MO)
      TET1=TET1+ET1(MO)
      TET2=TET2+ET2(MO)
      TET3=TET3+ET3(MO)
      TET4=TET4+ET4(MO)
      TET5=TET5+ET5(MO)
      TET6=TET6+ET6(MO)
      TETPH=TETPH+ETPH1(MO)
      TUSI=TUSI+USI1(MO)
      TWSET=TWSET+WSET1(MO)
      TSGW1=TSGW1+SGW11(MO)
      IF(MO-12)83,54,83
   54 WRITE(6,104) NYR
  104 FORMAT(1H1,38X,'HYDROLOGIC SIMULATION OUTPUT FOR THE YEAR',I5)
      WRITE(6,105)
  105 FORMAT(///27X,'JAN',5X,'FEB',5X,'MAR',5X,'APR',5X,'MAY',5X,'JUN',
     15X,'JLY',5X,'AUG',5X,'SEP',5X,'OCT',5X,'NOV',5X,'DEC',3X,'ANNUAL')
      WRITE(6,202) (PR1(L),L=1,12),TPR
      WRITE(6,203) (TA1(L),L=1,12)
      WRITE(6,205) (P1(L),L=1,12)
      WRITE(6,207) (AK1(L),L=1,12)
      WRITE(6,208) (AK2(L),L=1,12)
      WRITE(6,209) (AK3(L),L=1,12)
      WRITE(6,210) (AK4(L),L=1,12)
      WRITE(6,211) (AK5(L),L=1,12)
      WRITE(6,212) (AK6(L),L=1,12)
      WRITE(6,213) (AK6(L),L=1,12)
      WRITE(6,215) (WS1(L),L=1,12)
      WRITE(6,216) (SMLT1(L),L=1,12),TSMLT
      WRITE(6,217) (ET1(L),L=1,12),TET1
      WRITE(6,218) (ET2(L),L=1,12),TET2
      WRITE(6,219) (ET3(L),L=1,12),TET3
      WRITE(6,220) (ET4(L),L=1,12),TET4
      WRITE(6,221) (ET5(L),L=1,12),TET5
      WRITE(6,222) (ET6(L),L=1,12),TET6
      WRITE(6,223) (ETPH1(L),L=1,12),TETPH
      WRITE(6,224) (WSET1(L),L=1,12),TWSET
      WRITE(6,225) (SM1(L),L=1,12)
      WRITE(6,226) (SM2(L),L=1,12)
      WRITE(6,227) (SM3(L),L=1,12)
      WRITE(6,228) (SM4(L),L=1,12)
      WRITE(6,229) (SM5(L),L=1,12)
      WRITE(6,230) (SM6(L),L=1,12)
      WRITE(6,231) (SI1(L),L=1,12),TSI
      WRITE(6,232) (USI1(L),L=1,12),TUSI
      WRITE(6,236) (DTRS1(L),L=1,12),TDTRS
      WRITE(6,214) (ROUT1(L),L=1,12),TROUT
      WRITE(6,234) (QC1(L),L=1,12),TQC
```

Table D3. Continued.

```
      WRITE(6,233) (GWA(L),L=1,12),TGWA
      WRITE(6,234) (UGWA(L),L=1,12),TUGWA
      WRITE(5,235) (GW31(L),L=1,12),TGW3
      WRITE(6,236) (GW21(L),L=1,12)
      WRITE(6,237) (GW11(L),L=1,12)
      WRITE(5,238) (DPGW1(L),L=1,12)
      WRITE(6,231) (SGW11(L),L=1,12),TSGW1
      WRITE(6,271) (AIR1(L),L=1,12)
      WRITE(6,272) (AIR2(L),L=1,12)
      WRITE(6,273) (AIR3(L),L=1,12)
      WRITE(6,274) (AIR4(L),L=1,12)
      WRITE(6,275) (AIR5(L),L=1,12)
      WRITE(6,276) (AIR6(L),L=1,12)
  271 FORMAT(1H ,'1 BEETS    IRRIG(IN/AC)',12F8.2)
  272 FORMAT(1H ,'2 CORN     IRRIG(IN/AC)',12F8.2)
  273 FORMAT(1H ,'3 GRAIN    IRRIG(IN/AC)',12F8.2)
  274 FORMAT(1H ,'4 ALFALFA  IRRIG(IN/AC)',12F8.2)
  275 FORMAT(1H ,'5 PASTURE  IRRIG(IN/AC)',12F8.2)
  276 FORMAT(1H ,'6 LD PHYT  IRRIG(IN/AC)',12F8.2)
  202 FORMAT(1H ,'PRECIPITATION(IN)',5X,13F8.2)
  203 FORMAT(1H ,'AVERAGE TEMPERATURE    ',12F8.2)
  204 FORMAT(1H0,'CANAL DIVERSIONS',5X,13F8.0)
  205 FORMAT(1H ,'PERCENT DAYLIGHT HOURS',12F8.2)
  207 FORMAT(1H ,'1 BEETS KC COEF',7X,12F8.2)
  208 FORMAT(1H ,'2 CORN KC COEF',8X,12F8.2)
  209 FORMAT(1H1,'3 GRAIN KC COEF',7X,12F8.2)
  210 FORMAT(1H ,'4 ALFALFA KC COEF',5X,12F8.2)
  211 FORMAT(1H ,'5 PASTURE KC COEF',5X,12F8.2)
  212 FORMAT(1H ,'6 LAND PHRYTS KC COEF ',12F8.2)
  213 FORMAT(1H ,'7 WATER PHRYTS KC COEF',12F8.2)
  215 FORMAT(1H0,'ACCUM SNOW STORAGE',4X,13F8.2)
  216 FORMAT(1H ,'SNOW MELT',13X,13F8.2)
  217 FORMAT(1H ,'E. T. OF BEETS',8X,13F8.2)
  218 FORMAT(1H ,'E. T. OF CORN',9X,13F8.2)
  219 FORMAT(1H ,'E. T. OF GRAIN',8X,13F8.2)
  220 FORMAT(1H0,'E. T. OF ALFALFA',6X,13F8.2)
  221 FORMAT(1H ,'E. T. OF PASTURE',6X,13F8.2)
  222 FORMAT(1H ,'E. T. OF LAND PHYTS',3X,13F8.2)
  223 FORMAT(1H ,'E. T. OF WATER PHYTS',2X,13F8.2)
  224 FORMAT(1H ,'E. T. OF WATER SURFACE',13F8.2)
  225 FORMAT(1H0,'SOIL MOIST BEETS (IN) ',12F8.2)
  226 FORMAT(1H ,'SOIL MOIST CORN (IN)  ',12F8.2)
  227 FORMAT(1H ,'SOIL MOIST GRAIN (IN) ',12F8.2)
  228 FORMAT(1H ,'SOIL MOIST ALFLFA (IN)',12F8.2)
  229 FORMAT(1H ,'SOIL MOIST PASTRE (IN)',12F8.2)
  230 FORMAT(1H0,'SOIL MOIST LD PHT (IN)',12F8.2)
  201 FORMAT(1H ,'MEASURED INFLOW',7X,13F8.0)
  206 FORMAT(1H ,'CHANGE IN RES STORAGE ',13F8.0)
  214 FORMAT(1H ,'CALCULATED RES OUTFLOW',13F8.0)
  232 FORMAT(1H ,'UNMEAS SUR INFLOW(AF) ',13F8.0)
  233 FORMAT(1H ,'DEEP PERCOL TO G W(AF)',13F8.0)
  234 FORMAT(1H ,'GROUNDWATER INFLOW(AF)',13F8.0)
  235 FORMAT(1H ,'DEEP PERCL+GW INFL(AF)',13F8.0)
  236 FORMAT(1H ,'DELAY LEVEL 2 (AF)',4X,12F8.0)
  237 FORMAT(1H0,'LEVEL 1 BEFOR OTFL(AF)',12F8.0)
  239 FORMAT(1H ,'LEVEL 1 AFTER OTFL(AF)',12F8.0)
  231 FORMAT(1H ,'GW TO SUR FM LEV 1(AF)',13F8.0)
   82 WRITE(6,259) NYR
  259 FORMAT(1H1,38X,'ECONOMIC SIMULATION OUTPUT FOR THE YEAR',I5)
      WRITE(6,120)
  120 FORMAT(1H0,28X,'BEETS ',6X,' CORN ',6X,'GRAIN ',5X,'ALFALFA',4X,'
     1PASTURE',4X,'LND PHYTS',3X,'WTR PHYTS',4X,'WATER')
      WRITE(6,126)AREA(1),AREA(2),AREA(3),AREA(4),AREA(5),AREA(6),
     1AREA(7),WSAR
      WRITE(6,114)RD(1),RD(2),RD(3),RD(4),RD(5),RD(6)
      WRITE(6,115)WHC(1),WHC(2),WHC(3),WHC(4),WHC(5),WHC(6)
      WRITE(6,116)AW(1),AW(2),AW(3),AW(4),AW(5),AW(6)
      WRITE(6,121)YET(1),YET(2),YET(3),YET(4),YET(5),YET(6),TETPH,
     1TWSET
      WRITE(6,131)AIR(1),ATR(2),AIR(3),ATR(4),AIR(5),AIR(6)
      WRITE(6,122)APPIC(1),APRIC(2),APRIC(3),APRIC(4),APRIC(5)
      WRITE(6,123)YIELD(1),YIELD(2),YIELD(3),YIELD(4),YIELD(5)
      WRITE(6,124)RETG(1),RETG(2),RETG(3),RETG(4),RETG(5)
      WRITE(5,128)COST(1),COST(2),COST(3),COST(4),COST(5)
      WRITE(6,125)RETN(1),RETN(2),RETN(3),RETN(4),RETN(5)
  126 FORMAT(1H0,'CROP AREA(AC)          ',8F12.0)
  114 FORMAT(1H0,'ROOT DEPTH (FT)        ',6F12.2)
  115 FORMAT(1H0,'AVA WTR HOLD CAP(IN/FT)',F11.2,5F12.2)
  116 FORMAT(1H0,'AVA WTR CAP (IN)       ',6F12.2)
  121 FORMAT(1H0,'SEASONAL E T(IN/AC)    ',8F12.2)
  131 FORMAT(1H0,'SEASON IRR DIV (IN/AC)',6F12.2)
  122 FORMAT(1H0,'CROP PRICE($/UNIT)     ',5F12.2)
  123 FORMAT(1H0,'CROP YIELD(UNIT/AC)    ',5F12.2)
  124 FORMAT(1H0,'GROSS RETURN($/AC)     ',5F12.2)
  128 FORMAT(1H0,'COST PER ACRE($/AC)    ',5F12.2)
  125 FORMAT(1H0,' NET  RETURN($/AC)     ',5F12.2)
      RETNV=0.
      DO 177 MM=1,5
  177 RETNV=RETNV+RETN(MM)*AREA(MM)
      WRITE(6,127)RETNV
  127 FORMAT(1H0,'TOTAL NET RETURN FROM THE ENTIRE AREA=',F12.0)
      TIRR=(AIR(1)*AREA(1)+AIR(2)*AREA(2)+AIR(3)*AREA(3)+AIR(4)*AREA(4)+
     1AIR(5)*AREA(5))/12.0
      WRITE(6,249)TIRR
  249 FORMAT(1H0,'TOTAL IRRIGATION WATER DIVERTED (ACRE-FEET)=',F12.0)
C
C         GROUNDWATER DELAY
C
   83 GW1=GW1+GW2
   10 GW2=GW3
  999 CONTINUE
      STOP
      END

END OF UNIVAC 1108 FORTRAN V COMPILATION.      0 *DIAGNOSTIC* MESSAGE(S)
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Table D4. Constant input hydrologic values for digital Cache Valley simulation model.

Symbol	Description	Value
CSI	Unmeasured surface inflow correlation coefficient (unmeasured surface inflow/ measured surface inflow)	.22
CMELT	Snowmelt correlation coefficient (snowmelt correlated surface inflow/measured surface inflow)	.30
CKS	Snowmelt equation constant	.20
CGW	Groundwater correlation coefficient (subsurface inflow/measured surface inflow)	.12
OCEFF	Fraction of canal diversions which is actually available for plant use	.25
SMES	Lower limit of soil moisture (inches/acre) at which potential evapotranspiration will occur	2.00
APH	Fraction of canal diversions which is used by phreatophytes considered as a crop	.02
CDP	Fraction of canal diversions which deep percolate to groundwater	.10

Table D5. Digital computer model output of hydrologic values, 1945.

HYDROLOGIC SIMULATION OUTPUT FOR THE YEAR 1945

	JAN	FEB	MAR	APR	MAY	JUN	JLY	AUG	SEP	OCT	NOV	DEC	ANNUAL
PRECIPITATION(IN)	.28	1.70	1.77	.83	2.76	3.55	.11	1.95	1.64	1.39	2.80	1.80	20.58
AVERAGE TEMPERATURE	24.30	30.90	33.60	40.80	53.80	55.10	68.40	66.60	54.10	49.50	30.30	24.30	
PERCENT DAYLIGHT HOURS	6.60	6.66	8.28	8.97	10.10	10.21	10.37	9.64	8.42	7.73	6.63	6.39	
1 BEETS KC COEF	.25	.25	.25	.25	.35	.66	1.10	1.25	1.14	.25	.25	.25	
2 CORN KC COEF	.25	.25	.25	.25	.37	.75	1.08	1.03	.65	.25	.25	.25	
3 GRAIN KC COEF	.25	.25	.25	.26	.50	1.54	1.12	.25	.25	.25	.25	.25	
4 ALFALFA KC COEF	.63	.73	.86	.98	1.08	1.13	1.11	1.06	.98	.90	.78	.64	
5 PASTURE KC COEF	.48	.58	.74	.86	.90	.93	.91	.91	.86	.79	.64	.52	
6 LAND PHRYTS KC COEF	.70	.70	.75	.81	.89	1.02	1.18	1.28	1.29	1.19	1.04	.86	
7 WATER PHRYTS KC COEF	.70	.70	.75	.81	.89	1.02	1.18	1.28	1.29	1.19	1.04	.86	
ACCUM SNOW STORAGE	2.64	2.03	1.30	.06	.00	.00	.00	.00	.00	.00	1.84	3.64	
SNOW MELT	.00	2.31	2.50	1.24	.06	.00	.00	.00	.00	.00	.96	.00	7.07
E. T. OF BEETS	.04	.11	.19	.36	1.17	2.37	6.78	6.73	3.23	.52	.11	.04	21.65
E. T. OF CORN	.04	.11	.19	.36	1.24	2.70	6.66	5.54	1.84	.52	.11	.04	19.35
E. T. OF GRAIN	.04	.11	.19	.37	1.68	5.54	6.91	1.35	.71	.52	.11	.04	17.55
E. T. OF ALFALFA	.11	.33	.64	1.41	3.62	4.06	6.84	5.70	2.78	1.87	.33	.11	27.79
E. T. OF PASTURE	.06	.25	.55	1.23	3.02	3.34	5.61	4.88	2.44	1.64	.27	.09	23.38
E. T. OF LAND PHYTS	.06	.28	.56	1.16	2.98	3.67	7.28	6.89	3.38	1.86	.33	.13	28.57
E. T. OF WATER PHYTS	.12	.32	.56	1.16	2.98	3.67	7.28	6.89	3.65	2.47	.44	.14	29.68
E. T. OF WATER SURFACE	.17	.45	.74	1.43	3.35	3.60	6.17	5.38	2.83	2.08	.42	.17	26.79
SOIL MOIST BEETS (IN)	8.78	9.00	9.00	9.00	9.00	9.00	7.89	8.20	8.74	9.00	9.00	8.96	
SOIL MOIST CORN (IN)	8.92	9.00	9.00	9.00	9.00	9.00	7.91	8.40	8.97	9.00	9.00	8.96	
SOIL MOIST GRAIN (IN)	4.33	6.00	6.00	6.00	6.00	5.67	4.87	5.47	6.00	6.00	6.00	5.96	
SOIL MOIST ALFLFA (IN)	7.06	9.00	9.00	9.00	8.86	8.91	7.25	8.37	8.81	8.33	8.96	8.86	
SOIL MOIST PASTRE (IN)	1.40	3.45	5.40	6.24	7.46	7.50	3.54	3.19	5.93	5.68	6.37	6.29	
SOIL MOIST LD PHT (IN)	.92	2.95	4.90	5.81	6.96	8.96	5.05	2.21	1.79	1.31	1.94	1.81	
MEASURED INFLOW	38082.	43690.	56534.	89771.	168788.	194011.	112471.	85342.	63225.	54845.	52291.	59790.	1018840.
UNMEAS SUR INFLOW(AF)	8378.	9612.	12437.	19750.	29700.	29700.	5624.	4267.	3161.	2742.	2615.	2989.	130975.
CHANGE IN RES STORAGE	7060.	-3920.	-9140.	7790.	5070.	2200.	-7550.	4500.	-10200.	10140.	-1960.	1340.	5330.
CALCULATED RES OUTFLOW	48333.	76313.	96438.	113950.	170283.	177911.	49368.	48982.	70203.	73662.	87366.	80208.	1093014.
CANAL DIVERSIONS	0.	0.	0.	0.	96375.	155625.	239319.	154011.	95928.	0.	0.	0.	741258.
DEEP PERCOL TO G W(AF)	0.	5404.	20468.	12140.	16655.	17861.	23932.	15401.	11181.	4550.	4694.	0.	132286.
GROUNDWATER INFLOW(AF)	4570.	5243.	6784.	10773.	20255.	23281.	13497.	10241.	7587.	6581.	6275.	7175.	122261.
DEEP PERCL+GW INFL(AF)	4570.	10647.	27253.	22913.	36909.	41142.	37428.	25642.	18768.	11131.	10969.	7175.	254547.
DELAY LEVEL 2 (AF)	4962.	4570.	10647.	27253.	22913.	36909.	41142.	37428.	25642.	18768.	11131.	10969.	
LEVEL 1 BEFOR OTFL(AF)	18140.	14032.	11586.	16440.	35472.	40649.	57234.	69759.	72308.	61796.	49666.	35964.	
LEVEL 1 AFTER OTFL(AF)	9070.	7016.	5793.	8220.	17736.	20325.	28617.	34880.	36154.	30898.	24833.	17982.	
GW TO SUP FM LEV 1(AF)	9070.	7016.	5793.	8220.	17736.	20325.	28617.	34880.	36154.	30898.	24833.	17982.	241523.
1 BEETS IRRIG(IN/AC)	.00	.00	.00	.00	.00	.00	22.24	20.37	8.48	.00	.00	.00	
2 CORN IRRIG(IN/AC)	.00	.00	.00	.00	.00	.00	21.83	16.34	3.07	.00	.00	.00	
3 GRAIN IRRIG(IN/AC)	.00	.00	.00	.00	.00	6.63	23.98	.00	.00	.00	.00	.00	
4 ALFALFA IRRIG(IN/AC)	.00	.00	.00	.00	2.64	2.28	20.28	19.51	6.29	.00	.00	.00	
5 PASTURE IRRIG(IN/AC)	.00	.00	.00	.00	5.65	.00	6.15	10.32	14.17	.00	.00	.00	
6 LD PHYT IRRIG(IN/AC)	.00	.00	.00	.00	5.25	8.48	13.05	8.40	5.23	.00	.00	.00	

Table D6. Digital computer model output of economic values, 1945.

ECONOMIC SIMULATION OUTPUT FOR THE YEAR 1945

	BEETS	CORN	GRAIN	ALFALFA	PASTURE	LND PHYTS	WTR PHYTS	WATER
CROP AREA(AC)	9824.	8967.	47208.	49799.	51300.	17611.	20660.	7567.
ROOT DEPTH (FT)	6.00	6.00	4.00	6.00	3.00	6.00		
AVA WTR HOLD CAP(IN/FT)	1.50	1.50	1.50	1.50	2.50	1.50		
AVA WTR CAP (IN)	9.00	9.00	6.00	9.00	7.50	9.00		
SEASONAL E T(IN/AC)	20.29	17.98	14.12	27.79	23.38	28.57	29.68	26.79
SEASON IRR DIV (IN/AC)	51.10	41.24	30.61	51.00	36.30	10.10		
CROP PRICE($/UNIT)	16.60	7.00	1.05	21.00	5.50			
CROP YIELD(UNIT/AC)	16.85	17.98	54.96	3.98	6.09			
GROSS RETURN($/AC)	287.74	125.83	61.17	88.12	33.49			
COST PER ACRE($/AC)	169.02	102.67	68.33	64.83	28.55			
NET RETURN($/AC)	118.72	23.16	-7.16	23.29	4.94			

TOTAL NET RETURN FROM THE ENTIRE AREA= 2449798.